c. 2

Saskatchewan
Energy and Mines

Saskatchewan
Geological Survey

Miscellaneous Report 89-4

Summary of Investigations 1989, Saskatchewan Geological Survey

91-00753/

Summary of Investigations 1989

ERRATA

Geology of the Careen Lake West Area (update) is not included in the map package

Page 17 - last line of figure caption should read:

...2, M-10 showing; 3, Wapa 13 showing.

Page 23 - in Table 1 the following line is missing from Sample Descriptions:

8922-334	*6087700N 558970E*	*Wapa 13*	*15 cm wide milky quartz vein*

Page 191 - the photograph shown below should appear beside the caption **Precambrian Laboratory, La Ronge, April 1989**

Saskatchewan
Energy and Mines

Saskatchewan
Geological Survey

Miscellaneous Report 89-4

Summary of Investigations 1989, Saskatchewan Geological Survey

Printed under the authority of the
Minister of Energy and Mines

Although the Department of Energy and Mines has exercised all reasonable care in the compilation, interpretation and production of this report, it is not possible to ensure total accuracy, and all persons who rely on the information contained herein do so at their own risk. The Department of Energy and Mines and the Government of Saskatchewan do not accept liability for any errors, omissions or inaccuracies that may be included in, or derived from, this report.

Editor and Reviewer:

R. Macdonald

Reviewers:

T.I.I. Sibbald
D.F. Paterson
P. Guliov

Production Editors:

C.T. Harper
N. Richmond-Johnson

Production Assistant:

B. Czornobay

ISSN 0228 5657
Printed by Printco Graphics Inc.

Foreword

This publication presents preliminary results of the 1989 geoscience program of Saskatchewan Energy and Mines and includes contributions from a number of other institutions including the Geological Survey of Canada, University of Saskatchewan, University of Regina, Saskatchewan Research Council, University of Waterloo, University of California (Santa Cruz) and the University of Kansas.

The five-year Canada-Saskatchewan Mineral Development Agreement (MDA) expired on March 31, 1989 and brought about a marked decrease in the Geological Survey of Canada's participation in northern geoscience projects. In the absence of a successor MDA a new provincial program, the Saskatchewan Mineral Industry Diversification Program (MIDP), was introduced in order to maintain geoscience support to industry.

The 1984-89 MDA focussed primarily on detailed geological mapping of the gold belts of the province. The new program maintains a strong commitment to precious metals but is considerably broader in scope and includes projects on base-metals, uranium, rare earths, diamonds and a variety of industrial minerals. In addition, after a hiatus of several years, reconnaissance mapping was resumed in the northeast corner of the province. Approximately 3000 km^2 were mapped in the current year out of an area of 15,600 km^2 that lacks coverage at the 1:100,000 scale.

Stratigraphic studies of subsurface strata in the southern part of the province, with special reference to the potential for oil and natural gas development, are reviewed in this publication. Work was carried out in-house as well as by contract with the Geology Department at the University of Regina.

I would like to thank all of the authors who contributed to the 1989 Summary of Investigations as well as acknowledge with gratitude the efforts of the editorial, cartographic and stenographic staff in maintaining the high standard of publication.

L.S. Beck
Executive Director
Geology and Mines Division

November, 1989

Contents

Page

Foreword ... iii

Contents ... v

Northern Geoscience Program

Review of the Northern Geoscience Program 1989-90 ... *R. Macdonald and T.I.I. Sibbald* 1

Northern Reconnaissance:

* Reconnaissance Bedrock Geological Mapping, Misaw Lake Area (NTS 64M-NE) ... *B.A. Reilly* 5

* Bedrock Geological Mapping, Hatle Lake Area (Part of NTS 64M-13 and -14) ... *B.A. Reilly* 11

Gold Belt Geology:

* Bedrock Geological Mapping, Maynard-Wapawekka Lakes Area (Part of 73I-16, 63L-13, 63M-3 and 73P-1) ... *G.D. Delaney* 17

* Bedrock Geological Mapping, Sadler Lake Area (Part of NTS 63M-4 and -5) ... *W.L. Slimmon* 28

Glennie-Kisseynew P-T-t Study 1989: Fieldwork and Preliminary Results ... *D. Perkins* 34

* Structural Controls on Gold Deposits in the La Ronge Domain, Saskatchewan: A Progress Report ... *R.G. Roberts* and P.L. Schwann 36

* La Ronge Gold Belt Geology: Gold Deposits in the Byers Fault Area (part of 64D-4) ... *P.L. Schwann* 41

Metallic Minerals Diversification:

* Geology of the Douglas Lake - Phantom Lake area (Part of NTS 63K-12 and -13) ... *D.J. Thomas* 44

Lithogeochemical Studies in the Flin Flon - Amisk Lake Area and Glennie Domain ... *B.R. Watters* 55

The Development of Highly-strained Rocks in the Pelican Window During High-grade Metamorphism and Pervasive Anatexis ... *J.F. Lewry, R. Macdonald and M.L. Stauffer* 58

* Base Metal Deposits and Geology of the Early Proterozoic Hanson Lake Metavolcanics ... *T.I.I. Sibbald* 66

Beryl Pegmatites in the Jan Lake Area (NTS 63L and 63M) ... *D.G. MacDougall* 71

Field Observations on the Frontier, Box and Athona Granites, Goldfields Area, Saskatchewan ... *E.C. Appleyard* 82

The Wollaston Group and its Underlying Archean Basement in Saskatchewan .... *I.R. Annesley and C. Madore* 87

Mineral Deposit Studies: Raven-Horseshoe Uranium Deposit, Preliminary Report .... *D.H. Quirt* 92

A Reinterpretation of Lake Sediment Geochemistry in the NEA/IAEA Athabasca Test Area .... *Michel Mellinger* 95

* Field Relationships and Kinematic Indicators in the Virgin River Shear Zone .... *J. Carolan and K.D. Collerson* 98

Structural Relationships of the Western Granulite Domain and the Virgin River Shear Zone .... *J. Carolan, C.H. Crocker and K.D. Collerson* 102

* Geology of Early Proterozoic Gneissic Rocks, Black Birch Lake Area: Progress Report 2 .... *S. Orrell and M.E. Bickford* 105

Mineralized Core Collection .... A. Gracie 110

Three Precambrian Databases .... R. Macdonald 112

Petroleum Geology Program

The Earlie Formation (Cambrian) in Saskatchewan .... *D.F. Paterson* 117

* Geology and Natural Gas Production of the Upper Cretaceous Medicine Hat Sandstone, Southeastern Saskatchewan .... *C.F. Gilboy* 121

Distribution of Lower Paleozoic Strata in the Vicinity of the Meadow Lake Escarpment, West-central Saskatchewan .... *F.M. Haidl* 125

* Palynology of the Shaunavon and Gravelbourg Formation of Southern Saskatchewan .... *K.L. Kreis* 133

Preliminary Report on a Pore Geometry Reservoir Model for the Carbonate Buildups in the Winnipegosis Formation (Devonian) in Southeast Saskatchewan .... *Melinda Yurkowski* 137

Sedimentology and Geochemistry of the Bakken Formation (Devonian-Mississippian) in Southern Saskatchewan .... *Ramez Karma and G.R. Parslow* 141

Industrial Mineral Program

Review of Industrial Mineral Investigations 1989-90 .... *P. Guliov* 151

Building Stone Investigations in the Creighton - Denare Beach Area .... *P. Guliov* 153

Three Major Processes that Occur During the Deposition and Preservation of Potash Salts of the Prairie Evaporite in Saskatchewan .... *D.M. Lane* 157

Kimberlite (Diamond) Studies

* Regional Phanerozoic Anomalies of Saskatchewan .... *M.L. Gent* 162

Sm-Nd Isotopic Restraints on the Age of Buried Precambrian Basement in Central and Southern Saskatchewan: Implications for Diamond Exploration .... *K.D. Collerson* 168

The Sturgeon Lake Kimberlite - An Investigation into the Geochemical Response Exhibited by Organic Sample Media .... *C.E. Dunn* 172

Appendices

Abstracts of Recent Saskatchewan Energy and Mines Publications and Papers by Staff of the Saskatchewan Geological Survey (with Reprints issued) 181

Acknowledgements 189

Organization Chart and Staff Photographs 190

Staff List .... inside back cover

Asterisked reports have accompanying maps or sections. A list of these may be found on the inside cover of the map package.

Northern Geoscience Program

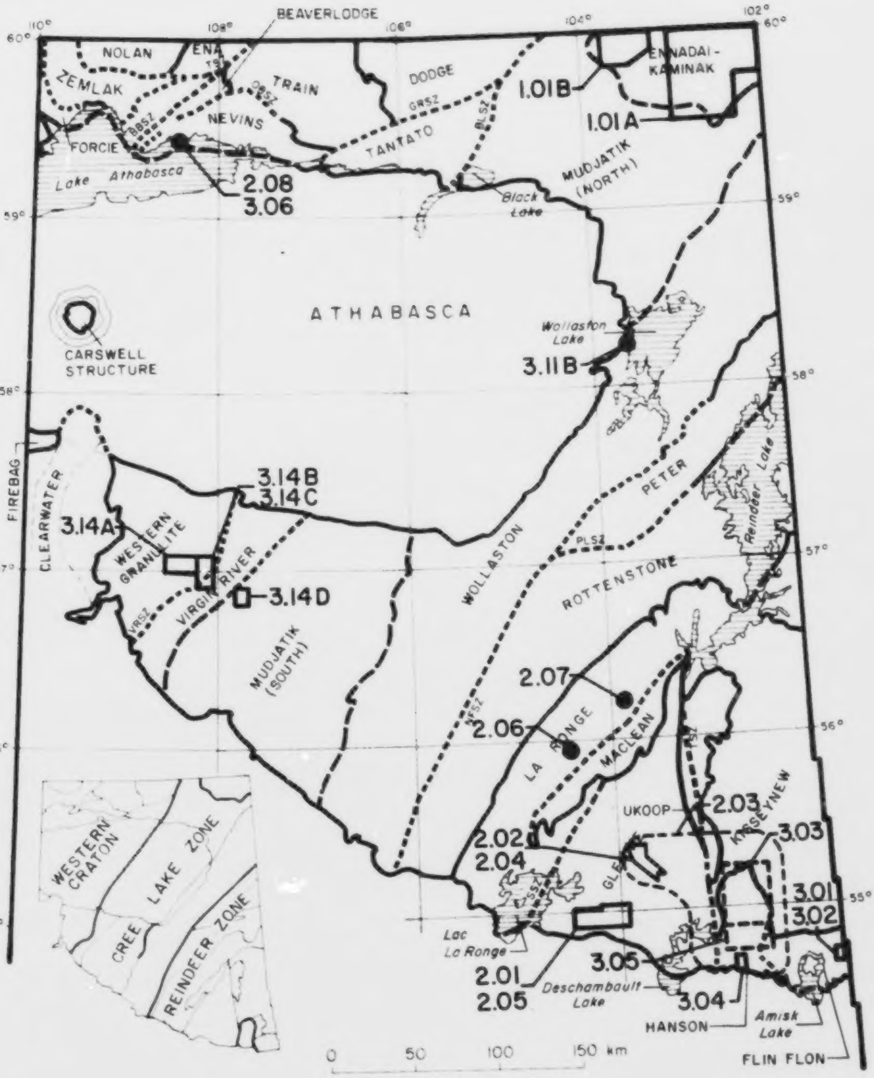

BEAVERLODGE
110°
108°
106°
104°
102°
60°
NOLAN
ENA
TSL
ZEMLAK
TRAIN
GRSZ
DODGE
NEVINS
BBSZ
FORCIE
Lake Athabasca
2.08
3.06
59°
TANTATO
GRSZ
PLSZ
1.01B
ENNADAI-KAMINAK
1.01A
MUDJATIK (NORTH)
Black Lake
ATHABASCA
CARSWELL STRUCTURE
Wollaston Lake
3.11B
58°
FIREBAG
CLEARWATER
3.14A
WESTERN GRANULITE
3.14B
3.14C
VIRGIN RIVER
VRSZ
3.14D
MUDJATIK (SOUTH)
WOLLASTON
PETER
PLSZ
ROTTENSTONE
Reindeer Lake
57°
2.07
2.06
LA RONGE
MACLEAN
NFSZ
56°
UKOOP
2.03
KISSEYNEW
3.03
2.02
2.04
GLE
3.01
3.02
55°
Lac La Ronge
2.01
2.05
Deschambault Lake
3.05
3.04
HANSON
Amisk Lake
FLIN FLON
0
50
100
150 km
WESTERN CRATON
CREE LAKE ZONE
REINDEER ZONE

Figure 1 – Location of projects or reports in hand 1989-90 (excluding compilation maps). Numbers on map refer to the Mineral Industry Diversification Program (MIDP) project number listed in first column opposite. The base map shows in abbreviated form the location of the main lithostructural domains in northern Saskatchewan.

Review of the Northern Geoscience Program 1989-90

R. Macdonald and T.I.I. Sibbald

Macdonald, R. and Sibbald, T.I.I. (1989): Review of the Northern Geoscience Program 1989-90; *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

With the conclusion of the Canada-Saskatchewan Mineral Development Agreement (MDA) 1984-89 on March 31 of this year, the Saskatchewan Geological Survey embarked this year on a new provincially-funded geoscience program, the Mineral Industry Diversification Program (MIDP). This program has a broader coverage of the province than the recent MDA, but the emphasis is still predominantly in the north, and all northern projects reported in this publication have been funded operationally under the MIDP (Figure 1).

Following the upswing in markets over the past year or two, gold is now joined by base metals as a commodity of interest to exploration industry in northern Saskatchewan. The completion of the airborne gradiometric survey over the eastern part of the Shield edge east of

Proj No.	*Data No.**	*Area or Short Title*	*Project Leader*	*Notes*
1. Northern Bedrock Reconnaissance Mapping				
1.01A	8923	Misaw Lake Area	B.A. Reilly	F,M
1.01B	8923	Hatle Lake	B.A. Reilly	F,M
2. Gold Belt Geology				
2.01	8922	Bedrock Remapping, Maynard-Wapawekka Lakes	G.D. Delaney	F,M
2.02	8930	Bedrock Remapping, Sadler Lake area	W.L. Slimmon	F,M
2.03	8936	P-T-t Studies	D. Perkins	F,J
2.04	8921	Glennie Geochemistry	B.R. Watters	W,C
2.05	8928	Southeastern Geochronology	Parrish	**
2.06	8929	Gold Deposit Structure	R.G. Roberts/ P.L. Schwann	F,C,M
2.07	8935	Byers Fault Gold Deposits	P.L. Schwann	F
2.08	8934	Gold Isotopes	R. Kerrich/ K. Kyser	0,C
3. Metallic Minerals Diversification				
3.01	8912	Bedrock Remapping Flin Flon - Creighton area	D.J. Thomas	F,M
3.02	8937	Flin Flon Geochemistry	B.R. Watters	F,C
3.03	8901	Pelican Window Deformation	J.F. Lewry *et al.*	F,J
3.04	8906	Mineral Deposits/ Geology, Hanson Lake area	T.I.I. Sibbald	F,M
3.05	8933	Beryl Pegmatites, Hanson Lake area	D.G. MacDougall	F
3.06	8938	Goldfields Gold Geochemistry	E..C. Appleyard	F,C
3.08	8916	Base Metals Review	Contract	0,W,C
3.09	8911	High Tech Minerals	D.G. MacDougall C.T. Harper	0,W
3.11	8907	Wollaston Group Stratigraphy	A. Annesley	W,F,C
3.12	8907	Raven-Horseshoe Uranium Deposit	D. Quirt	F,C
3.14A	8904	Geology/Geochronology Careen Lake West	C.H. Crocker/ K.D. Collerson	0,F,J,M
3.14B	8904	Geology/Geochronology Careen Lake East	J. Carolan/ K.D. Collerson	F,J,M
3.14C	8904	Virgin River Shear Zone	J. Carolan *et al.*	F,J
3.14D	8904	Geology/Geochronology Black Birch Lake	S. Orrell	F,J,M
3.15	8805	Mineralized Core Collection	A.J. Gracie	F,W
4. Kimberlite (Diamond) Studies				
4.02	8926	Sub-Phanerozoic Basement Studies	K.D. Collerson/ J.F. Lewry	0,C,W,***
A.		Sturgeon Lake Biogeochemistry	C. Dunn	E,J

* Database Number (formerly project number, used for samples etc.)
** Reported under Project 3.02
*** Covers all terrain in Saskatchewan south of the Shield
0 Report not included in this publication
F Fileld component in 1989
W Project covered wide area (not shown on map)
C Contract project in 1989
J Joint venture with SEM in 1989
E Externally contributed report
M Geological or geochemical map(s) in accompanying package

Limestone Lake (under the recent MDA), and the recent Cameco-Trimin base metal discovery at McIlvenna Bay, Hanson Lake has drawn attention to the potential for base metals in that region, particularly under the thin Paleozoic cover. Regional mapping and other studies under the MIDP have consequently supported gold and base metal exploration. Studies in uranium geology have also continued.

The new excitement in Saskatchewan geology is, of course, the diamond exploration play centred around Prince Albert and farther afield. A program of kimberlite studies initiated this year under the MIDP includes two hard rock projects.

The northern program has been grouped under four sub-programs: 1) Northern Bedrock Reconnaissance, 2) Gold Belt Geology, 3) Metallic Minerals Diversification and 4) Kimberlite (Diamond) Studies (Figure 1):

1. Northern Bedrock Reconnaissance

Projects 1.01A and 1.01B - The bedrock geology of about 15,600 km^2 of terrain in northern Saskatchewan still remains unmapped. This summer the 1:100,000 scale reconnaissance mapping program was resumed after a gap of several years by B.A. Reilly who mapped the Misaw Lake area (NTS 64M-NE). The terrain is very poorly exposed, and as the mapping was completed in 2 months, a start was made in the area around Hatle Lake in the adjoining sheet (NTS 64M-NW).

The Misaw Lake area is underlain extensively by high grade Mudjatik felsic gneisses. Low grade Hurwitz rocks overlie the gneisses at Hasbala and Many Islands Lakes, where rock exposure is better. The contact between the Mudjatik and Hurwitz rocks is generally highly strained and kinematic indicators indicate northwesterly thrusting of the Hurwitz over the gneisses.

Around Hatle Lake, Archean metavolcanics and metasediments of the Ennadai-(Rankin) greenstone belt occur in a broad synform which is enveloped by granitoid gneisses and granitoids of Mudjatik type. Carbonate and calc-silicate rocks of Hurwitz type have been mapped south and east of the Ennadai belt.

Exploration targets: Although economic mineralization has not been uncovered in the Mudjatik gneisses in the area, the significant gold mineralization found recently at Ithingo Lake farther south in the Mudjatik Domain illustrates a potential for mineralization. There is also potential for mineralization in the Hurwitz rocks, as shown by the Shear Lake gold deposit in the District of Keewatin. Another favourable exploration target is the shear zone underlying the Hurwitz which contains abundant gossans and pyritic quartz stringers. The most significant mineralization in the Hatle Lake area is the Nirdac Creek gold occurrence, where the gold is hosted in Archean iron formation and was remobilized during shearing. The Ennadai volcanics also have potential for massive base metal and shear-zone hosted gold mineralization.

Project 1.02 Compilation Bedrock Geology and Precambrian Databases - The coloured version of the Fond-du-Lac (NTS 74O) sheet was published during the year. The coloured version of the Pelican Narrows/Amisk Lake (NTS 63M/L) sheets and the black line version of the Tazin Lake (NTS 74N) sheet are in progress (Figure 2).

Work has continued on a number of Precambrian databases. A report is included here on the progress of the Precambrian Bibliography, Lexicon and Geochronological Database. These files are available informally outside house to interested persons.

2. Gold Belt Geology

Project 2.01 Bedrock Remapping, Wapawekka Lake area - G.D. Delaney who remapped in the Brownell Lake area in 1988, extended mapping westwards into

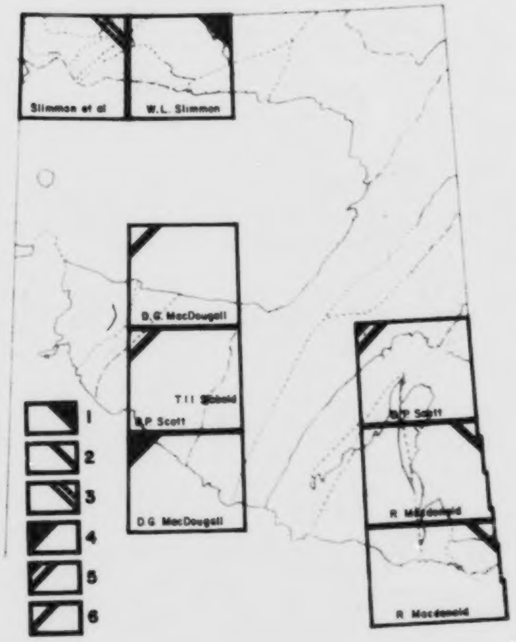


Figure 2 – Location of 1:250,000 scale compilation maps which were published or in progress in 1989-90.

Compilation Bedrock Geology

1 - Final colour version published;

2 - Final colour version in progress

3 - Black line in progress

Compilation Metallogenic

4 - Published

5 - Ready for press

6 - In progress

the Wapawekka Lake area this summer. Wapawekka Lake is largely occupied by metavolcanics and minor metasediments which are traversed by east-west trending high strain zones, and flanked on the north by plutons. The most favourable gold exploration targets occur along the margins of the main high strain zones.

Project 2.02 Bedrock remapping, Sadler Lake area - The Sadler Lake area, mapped by W.L. Slimmon, is mainly underlain by northwest-striking and northeast-dipping straight belts of psammopelitic to pelitic metasediments and mafic to intermediate metavolcanic rocks, with batholithic margins and minor intra-belt intrusions. Anastomosing ductile high strain zones contain protomylonites and intense stretching lineations.

Exploration Targets: Previous mineral exploration which mainly concentrated on base metals has delineated several conductive zones. Sulphide- bearing gossans are mainly associated with intermediate and felsic metavolcanics commonly in the vicinity of high strain zones. Samples from a sheared ultramafic body and a massive mafic to ultramafic intrusion have returned elevated nickel and chromium values.

Projects 2.03 and 2.04 - Dexter Perkins (U. of North Dakota, Project 2.03) has continued with P-T-t studies in the Glennie and Kisseynew Domains, and the Hanson Lake Block, tying in with other projects in this region. B.R. Watters (U. of Regina, Project 2.04) is analyzing samples for lithogeochemical characterization from the Sadler Lake area.

Project 2.05 Glennie Geochronology - Radiometric determinations are being carried out at the Geochronological Laboratory of the Geological Survey of Canada, Ottawa. Four samples were collected for determination by R. Parrish from the Brownell and Wapawekka Lakes area. These included 8822-375, younger granodiorite from the eastern end of the Carroll Lake Block; 8822-376, meta-arkose from the Wapawekka Lake Formation; 8822-377, granite from the Brownell Lake pluton; and 8822-378, granodiorite from the Maynard Creek pluton. Sample preparation has been completed and the results are due this winter.

Project 2.06 La Ronge Belt - Gold Deposits Structure - Structural studies of the Jolu and Jasper-James gold deposits and their surroundings were undertaken by R.G. Roberts (University of Waterloo) and P. Schwann. This work illustrates the way in which detailed structural analysis may be used to evaluate deposit geometry and determine the kinematic history of the shear zones that host mineralization. In contrast to conclusions from previous worker's investigations, strike-slip rather than dip-slip movements are recognized as fundamental in controlling gold-quartz vein emplacement.

Project 2.07 La Ronge Belt: Byers Fault Gold Deposits - P.L. Schwann initiated an investigation of gold deposits along the Byers Fault and subsidiary structures. Field mapping was carried out at Weedy Lake and Oven and Corner Lakes with the objective of documenting deposit geology and determining the structural controls on mineralization. Based on observations at Weedy Lake, favourable exploration targets are strongly foliated to mylonite zones in intrusives which exhibit pyritization, silicification, quartz veining and biotitization of hornblende.

Project 2.08 Gold Isotopes Study - A contract for stable and radiogenic isotopic investigations has been made with K. Kyser and co-workers at the University of Saskatchewan. Investigations will focus on polymetallic uranium-gold-PGE and related deposits in the Goldfields-Beaverlodge area north of Lake Athabasca with the objective of determining the nature and age of the mineralizing fluids. The recently commenced studies will utilize archived samples collected from the different deposits in the area.

3. Metallic Minerals Diversification

Project 3.01 Bedrock remapping, Creighton-Flin Flon area - D.J. Thomas initiated remapping of the Amisk rocks in the Flin Flon area this summer, immediately south of Creighton. Due to the excellent exposure and the need to establish relationships in detail, a mapping scale of 1:12,500 was chosen. About 3,500 m of the Amisk succession in this area has been divided into two assemblages, the Beaver Road assemblage, comprising a mainly subaqueous basic flow sequence, and an overlying Douglas Lake assemblage in which volcaniclastic deposits predominate over flows. A broad northwest-trending zone of shearing and alteration was identified as the Douglas Lake Structural Zone.

Exploration targets: Stratabound volcanogenic massive sulphide deposits are associated with rhyolitic flows throughout the Flin Flon-Snow Lake region. Most rhyolitic to dacitic rocks in the present area appear to be primarily shallow intrusives, but where they grade vertically into small extrusive lobes or domes flanked by felsic fragmentals, there is potential for massive volcanogenic sulphide mineralization. Numerous structurally-controlled auriferous quartz-sulphide veins occurring mostly in the Douglas Lake Structural Zone also merit further examination.

Project 3.02 Lithogeochemical studies in the Creighton-Flin Flon Area - B.R. Watters has collected samples mainly in support of the remapping program in the Creighton-Flin Flon area.

Project 3.03 Review of the Pelican Window, Hanson Lake Block - J.F. Lewry, M.R. Stauffer and R. Macdonald examined outcrops centred around Jan Lake in the Pelican Window of the Hanson Lake Block. In a major reinterpretation, four main lithological assemblages have been proposed, extensive ductile shear fabrics have been recognized, and a number of rock units previously interpreted as supracrustal have been assigned plutonic protoliths. Many of the rocks contain distinctive feldspathoclasts and other features indicating the broad contemporaneity of ductile shearing and anatexis.

Project 3.04 Hanson Lake Bedrock Geology - A small area (15 km2) surrounding the historic Western Nuclear lead-zinc deposit was geologically mapped at 1:20,000 scale and selected cores from the newly discovered McIlvenna Bay deposit nearby were logged by T.I.I. Sibbald. Both deposits are hosted by felsic rocks, comprising well laminated quartz sericite schist-chert sequences which appear to lie at two different stratigraphic levels. The McIlvenna Bay deposit occurs near the end of a cycle of rhyolite volcanism, whereas the Western Nuclear deposit was probably formed in an earlier cycle.

Project 3.05 Hanson Lake Beryl Pegmatites Study - Beryliferous granite pegmatites in the Sturgeon-Weir River and Hanson Lake areas were examined and sampled by D.G. MacDougall. Samples were analyzed petrographically and geochemically. Anomalous values of tin, niobium and cerium were detected in the Hanson Lake pegmatites, which generally appear richer in beryl and larger in size than those at Sturgeon-Weir.

Project 3.06 Goldfields Gold Deposit Geochemistry - Low grade granite-hosted gold mineralization, as manifested at the Box and Athona Mines and the Frontier prospect in the Goldfields area north of Lake Athabasca, has been the subject of several investigations in recent years. These have included detailed geological mapping, stable and radiogenic isotope, fluid inclusion and detailed structural studies. The present geochemical project by E.C. Appleyard (University of Waterloo) is designed to elucidate the origin of the granitic rocks and the source of the gold within them. Field observations are deemed to support existence of a low viscosity injected granite magma accompanied by diffuse fluids which permeated and 'granitized' the host rocks. The introduction of gold is interpreted as coeval, although the present concentration in quartz veins reflects remobilization.

Project 3.11 Wollaston Group Stratigraphy - This project jointly ventured with the Saskatchewan Research Council and six industry companies is being implemented by I. Annesley of the Council. Through field mapping of selected areas of the exposed Wollaston Domain and examinations of drill core from beneath the Athabasca Group, a more detailed stratigraphy of the Wollaston Group is being established. In conjunction, lithogeochemical signatures of different stratigraphic units are being quantified through compilation of existing and acquisition of new analytical data. This summer's field work indicated that some Wollaston Group meta-arkoses may be mylonitized Archean basement. This interpretation has significant implications for stratigraphy.

Project 3.12 Mineral Deposit Studies: Raven-Horseshoe Uranium Deposit - The project is being undertaken by D. Quirt of the Saskatchewan Research Council and is joint ventured with Cameco. Selected diamond drill cores from the low grade basement quartzite-hosted Raven and Horseshoe uranium deposits were logged and sampled for ore and clay mineral determination, as well as lithogeochemical and stable and radiogenic isotopic studies. Outcrops in proximity to the deposits were also examined. Preliminary findings indicate similarities with other basement hosted unconformity-type uranium deposits.

Project 3.14 Snowbird Transect - This program is a joint venture with the Universities of Kansas and California, Santa Cruz campus, aimed at examining a cross section of the Virgin River Shear Zone (in more regional terms the Snowbird Line). K.D. Collerson is the principal supervisor for the Santa Cruz team. M.E. Bickford is leaving the University of Kansas, and S. Orrell's supervisor is now R. Van Schmus. The program involves field mapping by three graduate students, with emphasis on geochemistry, and U-Pb/Nd-Sm isotopic and geochronological studies. The summer of 1989 was the second and final year of fieldwork.

C.H. Crocker examined the area west of the shear zone, including the anorthositic rocks of the Western Granulite Domain. The area is currently well exposed by burn and anorthosite is more extensive than previously mapped.

J. Carolan continued work on the shear zone itself, which has now been found to contain a number of lensoid low strain enclaves, including a body of nepheline syenite several kilometres long. Kinematic indicators have demonstrated a right-lateral motion on the shear zone.

S. Orrell completed mapping in the Black Birch Lake area, west of Ithingo Lake in the Mudjatik Domain.

Projects 3.15 and 3.16 Mineral Data and Compilation Maps - One new 1:250,000 metallogenic map, Ile-a-la-Crosse (73O) has been published. One sheet, Reindeer Lake South (64D) is awaiting publication and work is ongoing on the Mudjatik (74B) and Cree Lake (74G) map sheets.

The Saskatchewan Mineral Deposits Inventory (SMDI) is essentially up-to-date to 1988 in respect to information retrievable from non-confidential assessment work records. The manual file is now completely resident on microcomputer using Q&A software. Floppy diskettes in either IBM compatible ASCII or Q&A (Version 3.0) format will be available to the public in the near future.

Under the mineralized core collection project, 1356 m of new core has been collected this year from mineral properties tested for base metals (44 percent), gold (42 percent), PGE (8 percent) and uranium (6 percent). A total of 2,478 m of stratigraphic core was also collected from Paleozoic and Athabasca Group rocks.

4. Kimberlite (Diamond) Studies

Two projects of the new kimberlite studies program fall under the hard rock umbrella. Colin Dunn, of the Geological Survey of Canada in a jointly sponsored project has included a preliminary report on biogeochemical investigations over the environs of the Monopros Sturgeon Lake kimberlite body.

K.D. Collerson (University of California, Santa Cruz joint venture contract) has included a report on further Nd-Sm studies of the Sub-Phanerozoic Precambrian basement in southern Saskatchewan, which is relevant to diamond exploration strategies.

Reconnaissance Bedrock Geological Mapping, Misaw Lake Area (NTS 64M-NE)

B.A. Reilly

Reilly, B.A. (1989): Reconnaissance bedrock geological mapping, Misaw Lake area (NTS 64M-NE); *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

The map area is located in the extreme northeastern corner of Saskatchewan (NTS 64M-10, -15, -16 and part of -09). Manitoba borders to the east and the MacKenzie District of the Northwest Territories lies to the north. The map area encompasses approximately 2750 km^2 and is centred 190 km northeast of Stony Rapids. Extensive glacial deposits cover much of the map area. Bedrock exposure is extremely poor and is estimated at less than 1 percent. Mapping was completed at 1:63,360 scale using pace and compass traverses at 1.5 km spacing (5 km spacing was conducted in areas of predominantly bog and swamp) and publication is at 1:100,000 scale. Base camp was located on Misaw Lake from June 10 to June 27, then relocated to Patterson Lake from June 28 to August 8.

Previous work in the area dates back to 1893 and 1894, when J.B. Tyrrell mapped to the west along the Wholdaia River system, and to the north in the Kasba Lake area (Tyrrell 1898). The Geological Survey of Canada and the Saskatchewan Department of Mineral Resources jointly carried out an aeromagnetic survey of the entire Precambrian Shield area of Saskatchewan. Canadian Aero Service Limited was contracted in 1961 and the resulting aeromagnetic maps for the map area (Geological Survey of Canada 1961a, 1961b, 1961c and 1961d) were used by R.G. Agarwal as part of a regional correlation of geological and geophysical data (Agarwal 1962). Tremblay (1960) mapped the Phelps Lake area (NTS 64 M) at a 1:253,440 scale. More detailed mapping (1:63,360 scale) was conducted by Saskatchewan Energy and Mines during subsequent years. Lewry (1983) mapped the Kohn Lake area (NTS 64M SE) and Scott (1986) mapped the Phelps Lake (Southwest) area (NTS 64M SW). The east half of the Dutton Lake area, which is located in the southeast corner of the map area and includes the Many Islands metasedimentary belt, was mapped by Munday (1973). Weber et al. (1975) mapped northwestern Manitoba and Taylor (1963) mapped the southeastern District of Mackenzie, Northwest Territories.

1. Regional Geology

The map area lies within the Mudjatik Domain of the Cree Lake Zone (Lewry and Sibbald 1977, 1980). Hoffman (in press) proposes the name Hearne province for this zone. The Cree Lake Zone mainly comprises upper amphibolite to granulite facies granitoid orthogneisses and migmatitic paragneisses, with subordinate mafic gneisses derived from both metavolcanic and plutonic protoliths (Lewry and Collerson in press). Lewry and Collerson consider most of the zone to represent reworked Archean basement, though some paragneisses, migmatitic neosomal components and homogeneous late-kinematic granites are probably Early Proterozoic (Bickford et al. 1988). Hereafter, these rocks wil be referred to as the Mudjatik felsic gneisses.

Metasedimentary rocks in the Hasbala and Many Islands Lakes areas consist of upper greenschist to lower amphibolite facies psammopelites, carbonates and minor calc-silicate rocks. These rocks resemble the Late Aphebian Hurwitz Group from the Northwest Territories (Bell 1970a, 1970b, Taylor 1963) and they are considered correlative, exhibiting a similar environment of deposition and metamorphic grade (Munday 1973). Contacts between the Hurwitz Group metasedimentary rocks and the Mudjatik felsic gneisses are highly strained but age relations indicate that the Hurwitz Group unconformably overlies the Mudjatik felsic gneisses.

2. Mudjatik Felsic Gneisses

The Mudjatik felsic gneisses in the map area are subdivided into two major units: tonalite to tonalitic gneiss and pink granite to granitic gneiss. Subordinate rock types are layered felsic gneiss, feldspar augen gneiss, migmatite and pegmatite dykes. The two major units exhibit diffuse boundaries and are gradational with each other. The subordinate rock types are intimately mixed with the dominant units and are typically not mappable.

a) Tonalite to Tonalitic Gneiss

Tonalite to tonalitic gneissic rocks (unit Mgd) dominate the southwestern part of the map area and extend in a northeastern direction to the Hasbala Lake area (Figure 1). Weathered surfaces are buff-white to grey, and fresh surfaces are typically dull grey. Textures range from homogeneous to very inhomogeneous and exhibit a well-developed foliation and/or gneissosity. Composition is predominantly tonalitic, but is locally granodioritic to dioritic. Fine- to medium-grained quartz, plagioclase, with minor potassium feldspar, and up to 15 percent biotite are the chief mineral components. Discontinuous wisps and lenses of biotite flakes alternate with the quartzofeldspathic matrix to define a millimetre scale gneissosity. Mafic and ultramafic inclusions of various shapes, ranging in size from a few centimetres to decimetres, are common.

b) Pink Granite to Granitic Gneiss

Pink granite to granitic gneiss (unit Mgn) crops out as an arcuate-shaped body in the north-central portion of the map area and as a linear belt south of Hasbala Lake extending southwest of Apipuyew Lake (Figure 1). This rock is characterized by a distinctive pink color which is light, pinkish red on weathered surfaces. Fresh surfaces are medium pink. Textures are generally homogeneous, equigranular and range from massive to foliated to gneissic. Grain size is predominantly medium, but local-

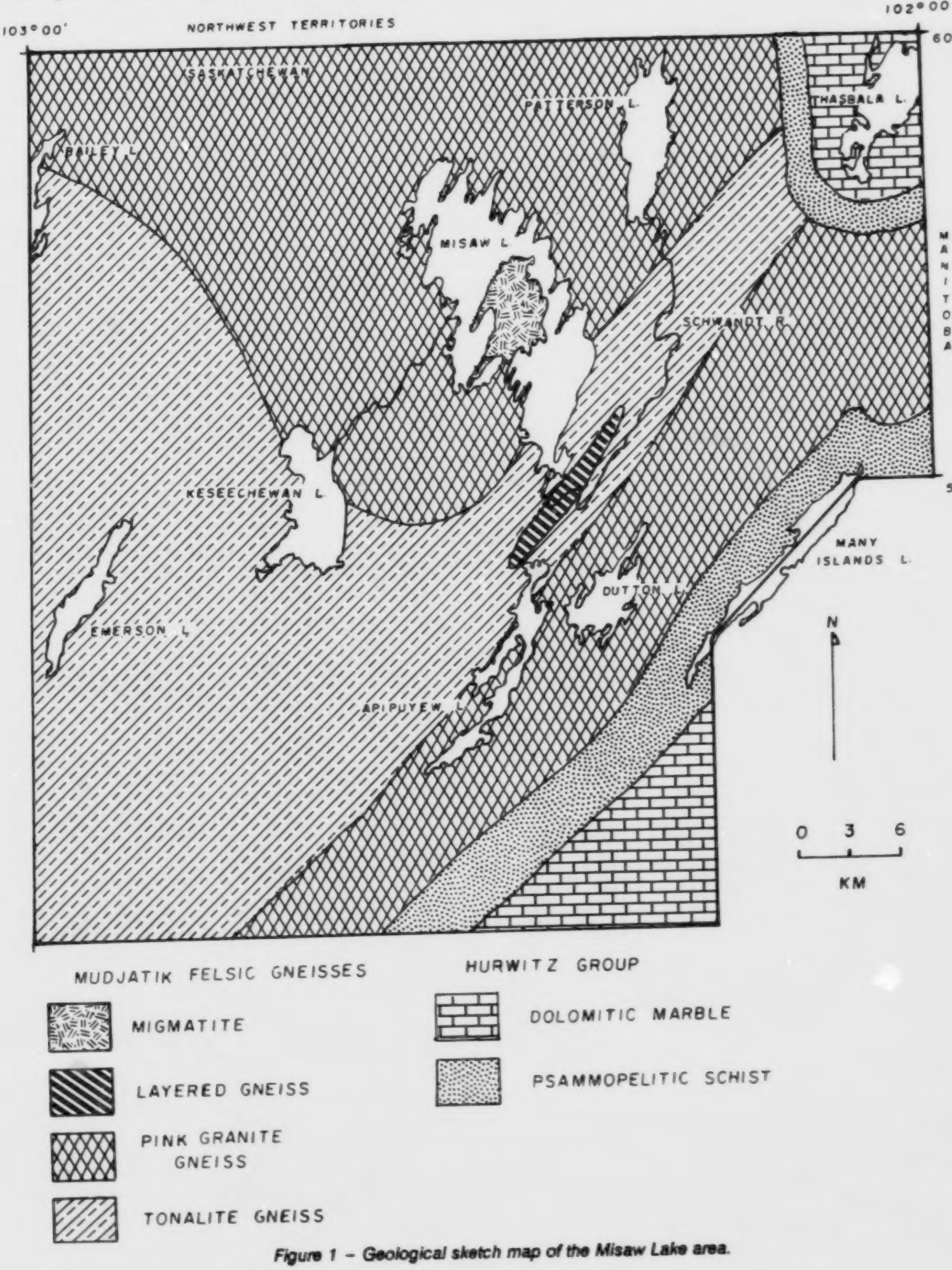

103°00'
NORTHWEST TERRITORIES
SASKATCHEWAN
102°00'
60°00'
THASBALA L.
PATTERSON L.
BAILEY L.
MISAW L.
MANITOBA
SCHWANDT R.
59°45'
KESEECHEWAN L.
MANY ISLANDS L.
DUTTON L.
EMERSON L.
N
APIPUYEW L.
0 3 6
KM
MUDJATIK FELSIC GNEISSES
MIGMATITE
LAYERED GNEISS
PINK GRANITE GNEISS
TONALITE GNEISS
HURWITZ GROUP
DOLOMITIC MARBLE
PSAMMOPELITIC SCHIST

Figure 1 – Geological sketch map of the Misaw Lake area.

ly fine and coarse grained. Variable proportions of potassium feldspar, quartz and plagioclase are the major mineral components. Biotite comprises less than 5 percent of the rock and hornblende is rare. Accessory magnetite and molybdenum are also present in some samples.

Gneissosity is defined in the pink granite by alternating mafic and quartzofeldspathic layers, or alternating potassium-rich and plagioclase-rich layers. The mafic layers are typically less than 5 mm thick, but locally as much as 10 cm thick, and comprise less than 10 percent of the rock. Layers rich in potassium feldspar average 2 to 3 cm thick. Adjacent to the Hurwitz Group metasediments in the Many Islands and Hasbala Lakes areas, the pink granite to granitic gneiss is porphyroclastic. Textures range from protomylonitic to ultramylonitic.

c) Layered Felsic Gneiss

Layered felsic gneiss (unit Mfl) forms a mappable rock unit south of Misaw Lake, along the Schwandt River (Figure 1). Elsewhere, it constitutes only a local component of the major rock units. Layering is manifest as alternating fine-grained mafic-rich layers, comprising mainly biotite and lesser hornblende in a quartzofeldspathic matrix, and medium- to coarse-grained (locally pegmatitic) felsic layers composed of quartz, plagioclase and potassium feldspar. The felsic layers range from tonalitic to granitic. The layers average a few centimetres in thickness, but millimetre and decimetre scale layering is also present. Alternating paleosome (mafic-rich) layers and neosome (felsic-rich) layers suggests a supracrustal origin for this unit.

d) Feldspar Augen Gneiss

Potassium feldspar porphyroblasts/clasts up to 3 cm in size comprise up to 50 percent of the rock in the feldspar augen gneiss unit (unit Mxn). The matrix is fine grained, quartzofeldspathic, and weathers buff to pink with pink fresh surfaces. Feldspar porphyroblasts/clasts vary from poorly defined augen-shaped subhedral grains to well-developed augens with symmetric and asymmetric tails. Field evidence suggests potassium feldspar grains originate from pegmatitic intrusions and/or potassic feldspar blastesis (i.e. porphyroblasts). The augen-shaped geometry, which defines this type of gneiss, was produced during cataclasis of potassium feldspar grains (i.e. porphyroclasts).

e) Migmatite

Various degrees of migmatization (unit Mz) are found locally in the two major rock units, as well as in the layered felsic gneiss. Numerous poorly exposed outcrops on Reynolds Peninsula at Misaw Lake exhibit the most extensive migmatization (Figure 1). Medium-grained pink granitic gneiss dominates, with minor phases of tonalitic gneiss, and probably represents older rocks. Paleosome material is represented as fine- to medium-grained mafic bodies which vary in composition and texture. Composition ranges from biotite to biotite-hornblende gneiss to amphibolite. Textures include decimetre-size schollen and agmatic blocks. Neosome mobilizate includes pink granitic to tonalitic melt, pegmatite and aplite. The passage from paleosome to neosome material varies from sharp to diffuse and the ratio of each migmatite component is variable. Compositional banding in the migmatitc rocks is manifest as alternating mafic and felsic layers exhibiting a schlieric, and less commonly stromatic texture. Feldspar augen gneiss and massive equigranular dioritic intrusions were found locally.

f) Pegmatite

Pegmatite (unit peg) is widespread throughout the map area and occurs as irregular shaped bodies or well-defined sills and dykes. Weathered surfaces are white to pinkish red and fresh surfaces are pink. They consist of potassium feldspar, quartz, minor plagioclase and biotite, and local magnetite. Textures are inhomogeneous and grain-size ranges from 1 to 5 cm. The pegmatite sills and dykes are generally about one metre thick and are locally zoned. Many phases of pegmatite generation were recognized. The earliest phase is manifest as potassium feldspar augen gneiss in which pegmatite has been deformed and metamorphosed with the country rock. Foliated and metamorphosed pegmatitic sills and dykes also indicate an early origin. Sharp-walled sills and dykes are massive and relatively fresh, suggesting post-tectonic emplacement.

3. Hurwitz Group

Metasedimentary rocks of the Hurwitz Group crop out in two localities (Figure 1): 1) in the extreme northeastern corner of the map area, near Hasbala Lake, extending further north and east into the Northwest Territories and Manitoba, respectively, and 2) in the southeastern corner of the map area near Many Islands Lake. The Hurwitz Group was first examined by Tyrrell (1898) at Kasba Lake, immediately north of Hasbala Lake, in the Northwest Territories. He called the limestone and quartzite units Huronian and considered them to be younger than the rocks he called Laurentian. Lord (1953) assigned quartzite, greywacke, conglomerate, dolomite, limestone and sedimentary schist to the Early Proterozoic, and Wright (1955) first used the name Hurwitz Group when he traced them into central Keewatin. Taylor (1963) recognized the rocks of the Hurwitz Group to be lithologically distinct from Archean metasedimentary rocks and regarded them as younger. Bell (1970a, 1970b) considered the Hurwitz to be Late Aphebian in age.

Hurwitz Group rocks in the map area consist of a basal psammopelitic schist overlain by a dolomitic marble with local calc-silicate layers. According to this description, these units may be correlated with the Watterson Formation of the Hurwitz Group (Aspler *et al*. 1989). Only the metasediments from the Hasbala Lake area will be described here as the metasediments of the Many Islands Lake area were described in detail by Munday (1973) .

a) Psammopelitic Schist

Psammopelitic schist (unit Hp) is found in sheared contact with the underlying Mudjatik Domain. Weathered surfaces are pale brown and fresh surfaces are dull grey. Very fine-grained quartzofeldspathic material contains up to 15 percent biotite which occurs as single platey interstitial flakes, or aggregates forming discontinuous layers and lenses in tectonic layering less than one centimetre thick. Minor chlorite, muscovite and carbonate is present.

Strata-parallel quartz veins locally comprise up to 15 percent of the psammopelitic schist. These veins are discontinuous and disrupted, averaging 10 cm x 3 cm due to the effects of shearing, boudinage, imbrication and folding.

Granitic sheets are intercalated with the psammopelitic schist near the contact between the Hurwitz Group metasediments and the Mudjatik felsic gneisses. The granitic sheets consist of aphanitic quartzofeldspathic material which weathers pink and possesses a dull grey fresh surface. Thickness of the sheets ranges from centimetres to decimetres. Contacts with the schist are highly strained and appear to be concordant. These granitic sheets are interpreted as apophysis or tectonic slices derived from the Mudjatik felsic gneisses.

b) Dolomitic Marble

Dolomitic marble (unit Hc) conformably overlies the psammopelitic schist. The rock weathers dull to dark brown. Fresh surfaces are whitish buff to greenish grey. Medium-sized grains (2-3 mm) of dolomite, with lesser calcite, are typically equigranular and relatively homogeneous. Minor phlogopite and actinolite are present. Internal bedding recognizable within the dolomitic marble ranges from 2 mm to 10 cm thick.

The dolomitic marble is locally interbedded with calc-silicate rock and/or cherty layers. The calc-silicate rocks weather light greenish buff to brown and fresh surfaces are greyish-green. Minerals present in the calc-silicate rock are medium-grained (1-2 mm) actinolite, tremolite and diopside, with lesser calcite and quartz. The cherty layers consist mainly of microcrystalline quartz with minor feldspar. The calc-silicate and cherty layers, which average 4-5 cm in thickness and comprise up to 20 percent of the rocks, are more competent than the marble and are typically boudinaged. The calc-silicate and cherty layers are also more resistant to weathering.

4. Diabase Dykes

Diabase dykes (unit Dd) were found in only a few localities. Fine to medium-grained hornblende and plagioclase occur consistently in equal proportions and the rock is massive, homogeneous, equigranular and locally fractured. Contacts with the country rock are sharp and range from linear to irregular. Dyke thickness varies from 50 to 150 cm. These dykes generally dip steeply and cross-cut all other rocks in the area, including the Hurwitz Group.

5. Structural Geology

The Mudjatik felsic gneisses have a flat, featureless aeromagnetic signature, which contrasts with the strong signature displayed by the Hurwitz Group metasediments. This featureless aeromagnetic signature is related to a regional, gently undulating, flat-lying to shallow dipping foliation and gneissosity which has been identified as the D1 fabric.

The D1 planar fabric is affected by at least two folding events recognized in isolated outcrops. Mesoscopic tight to isoclinal folds possess shallow dipping axial planes and fold axes which plunge shallowly to the east and northeast. Fold vergence varies from north to northwest. This folding is interpreted as a D2 event. Open, upright, mesoscopic folds are coaxial with D2 folds. These folds are M-type and exhibit neutral vergence. They refold D2 folds and represent a D3 event.

High strain zones located along the contact zones of Mudjatik felsic gneisses and the Hurwitz Group metasediments, interpreted as produced during deformational event D4, contain protomylonitic to ultramylonitic textures in both Mudjatik felsic gneisses and Hurwitz Group metasediments. Kinematic indicators, such as asymmetric shear folds and boudinaged and back-rotated quartz veins, give unequivocal sinistral shear sense in the Hasbala Lake area. Stretching lineations are subhorizontal and displacement along this contact is interpreted as due to thrusting of the Hurwitz Group rocks in a northwest direction over the underlying Mudjatik felsic gneisses. In the Many Islands Lake area, the kinematic indicators along the Mudjatik felsic gneisses - Hurwitz Group metasediments contact are ambiguous.

The northwest thrusting is compatible with the recent interpretation by Aspler *et al.* (1989) in the Ennadai Lake area, District of Keewatin, where the inferred direction of thrusting involving basement, Hurwitz Group and Kiyuk Group is based on the vergence of macrofolds and map scale geometric relationships. However, Hoffman (in press) indicates that vergence is not regionally consistent in the District of Keewatin. Northwest-directed thrusting is, however, consistent with a model for the Trans-Hudson Orogen proposed by Lewry *et al.* (1985). These authors envisage the deposition of a shelf sequence which includes the Hurwitz Group, and subsequent deformation of this sequence 1.87 Ga ago during collision from the southeast. The northwest-vergent fold and thrust terrane developed during this collision is compatible with the indicated shear transport direction along the Mudjatik felsic gneisses - Hurwitz Group metasediments contact in the Hasbala Lake area.

Late faulting (D5) is postulated from one north-south trending fault identified along the western perimeter of the map area. This structure was identified by its linear aeromagnetic signature but was not confirmed in the field. This postulated fault represents an extension of the Tabbenor system which can be traced to the southern edge of the Precambrian Shield in Saskatchewan.

6. Metamorphism

Metamorphic mineral assemblages in the granitoids and gneisses of the Mudjatik Domain consist of variable percentages of quartz, potassium feldspar, plagioclase, biotite and hornblende. The presence of extensive migmatization in the Reynolds Peninsula area and localized migmatitic rocks throughout the Mudjatik Domain indicates very high grade metamorphism. Regional metamorphic conditions are interpreted as upper amphibolite to granulite facies (Winkler 1979) in the Mudjatik felsic gneisses.

Hurwitz Group psammopelitic metasediments consist of biotite, chlorite, muscovite, plagioclase and quartz. Calcsilicate rocks and dolomitic marble contain actinolite, tremolite, diopside, phlogopite, carbonate, and quartz. This paragenesis corresponds to upper greenschist to lower amphibolite conditions (Winkler 1979).

Detailed petrographic work may substantiate whether the Hurwitz Group and Mudjatik felsic gneisses were affected by the same metamorphic events at different crustal levels (Lewry 1983) or whether high grade metamorphism and anatexis of the D1-D3 events affected only the Mudjatik felsic gneisses and the Hurwitz Group was deposited subsequently.

7. Economic Geology

a) Mineral Exploration

Laduboro Oil Limited (Assessment File 64M10-0002) completed a photogeological study of the Emerson Lake area in 1968. Canadian Aero service Limited was contracted to conduct an airborne radiometric and electromagnetic survey the following year. Ground follow-up indicated that the airborne anomalies were not significant.

In 1969, Jupiter Exploration Limited (Assessment File 64M10-0001) completed reconnaissance geological mapping and prospecting, an airborne radiometric survey, a biogeochemical survey and a photogeological study in the Dutton Lake area. Exploration was directed toward the uranium and base metal potential of the area but no significant occurrences were reported.

A geochemical and electromagnetic survey was carried out in 1969 and 1970 by C. Warren Hunt (Assessment File 64M16-0002) in the Chekask Lake area.

During 1971, Saskabo Mines Incorporated (Assessment File 64M16-0003) apparently drilled 16 holes along a 2000 m long magnetic anomaly at Ledford Lake. Copper and nickel values were reported from this work.

Taiga Consultants Limited (Assessment File 64M09-0008) conducted reconnaissance geology, scintillometer prospecting and regional scale sediment and lake water sampling in the Many Islands Lake area in 1978. No significant uranium occurrences were reported.

b) Exploration Targets

Mudjatik Felsic Gneisses:

No economic mineralization has yet been found in the rocks of the Mudjatik felsic gneisses in the map area. Subeconomic uranium concentrations have been mapped in pegmatite anatectic fractions in other parts of the Mudjatik Domain (Lewry and Sibbald 1979). The discovery of significant gold concentrations in the supracrustal rocks of the Mudjatik Domain in the Ithingo Lake area (Harper 1988) illustrates, however, the potential for mineral deposits to survive in high-grade terrains.

Hurwitz Group:

Munday (1973) reported an apparent lack of mineralization in the Hurwitz Group in the Many Islands Lake area and little is known about the Hurwitz Group rocks in the Hasbala Lake area. The economic potential of Hurwitz Group rocks may be considered in light of the presence of the Shear Lake gold deposit hosted by Hurwitz Group rocks in the District of Keewatin. Shear Lake is a vein-type gold deposit in fracture and shear zones (Raman et al. 1986) and brittle fault and breccia zones (Millar 1989). Millar (1989) suggests that the Hurwitz Group metasediments may be allochthonous in this area.

Mudjatik Felsic Gneisses-Hurwitz Group Contact Zones:

High strain zones which mark the contact between Hurwitz Group rocks and Mudjatik felsic gneisses are regarded as favourable exploration targets. Local gossanous zones, abundant quart veining and pyritic quartz stringers have been found along these contacts. High strain zones are favourable for gold concentration (Bursnal 1989) and uranium concentration (Lewry and Sibbald 1979).

8. References

Agarwal, R.G. (1962): Regional correlation of geological and geophysical data in the Lake Athabasca area, northern Saskatchewan; Sask. Dept. Miner. Resour., Rep. 75, 4p.

Aspler, L.B., Bursey, T.L. and Miller, A.R. (1989): Sedimentology, structure and economic geology of the Poorfish-Windy thrust-fold belt, Ennadai Lake area (65/C), District of Keewatin, and the shelf to foreland transition in the Foreland of Trans-Hudson Orogen; *in* Current Research, Pt. C, Geol. Surv. Can., Pap. 89-1C, p143-156.

Bell, R.T. (1970a): Preliminary notes on the Hurwitz Group, Padlei Map area, Northwest Territories; Geol. Surv. Can., Pap. 69-52, 13p.

Bell, R.T. (1970b): The Hurwitz Group - A prototype for deposition on metastable cratons; *in* Baer A.J. (ed.), Basins and Geosynclines of the Canadian Shield; Geol. Surv. Can., Pap. 70-40, p159-169.

Bickford, M.E., Collerson, K.D. and Lewry, J.F. (1988): U-Pb geochronology and isotopic studies of the Trans-Hudson Orogen in Saskatchewan; *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep., 88-4, p112-116.

Bursnall, J.T., Hodgson, C.J., Hubert, C., Kerrich, R.W., Marquis, P., Murphy, J.B., Osmani, I., Poulsen, H., Robert, F., Sanborn-Barrie, M., Stott, G., Williams, H.R. (1989): Mineralization and Shear Zones; Geol. Assoc. Can., Short Course Notes, v6, 300p.

Geological Survey of Canada (1961a): Geophysics Paper 1255G, Dutton Lake, Saskatchewan; NTS 64M-09.

_________ (1961b): Geophysics Paper 1256G, Emerson Lake, Saskatchewan; NTS 64M-10.

_________ (1961c): Geophysics Paper 1261G, Warren Lake, Saskatchewan; NTS 64M-15.

_________ (1961d): Geophysics Paper 1262G, Patterson Lake, Saskatchewan; NTS 64M-16.

Harper, C.T. (1988): Mudjatik Domain, geology and gold studies: Ithingo Lake; *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p42-48.

Hoffman, P.F. (in press): Subdivision of the Churchill province and extent of the Trans-Hudson orogen; *in* Lewry J.F. and Stauffer M.R. (eds.), The Early Proterozoic Trans-Hudson Orogen of North America, Geol. Assoc. Can., Spec. Pap.

Lewry, J.F. (1983): Geology of an area around Kohn Lake; Sask. Energy Mines, Rep. 222, 20p.

Lewry, J.F. and Sibbald, T.I.I. (1977): Variation in lithology and tectonometamorphic relationships in the Precambrian basement of northern Saskatchewan; Can. J. Earth Sci., v14, p1453-1467.

Lewry, J.F. and Sibbald, T.I.I. (1979): A review of pre-Athabasca basement geology in northern Saskatchewan; *in* Parslow G.R. (ed.), Uranium Exploration Techniques; Sask. Geol. Soc.., Spec. Publ. 4, p19-48.

Lewry, J.F. and Sibbald, T.I.I. (1980): Thermotectonic evolution of the Churchill Province in northern Saskatchewan; Tectonophysics, v68, p45-82.

Lewry, J.F., Sibbald, T.I.I. and Schledewitz, D.C.P. (1985): Variation in character of Archean rocks in the western Churchill Province and its significance; *in* Ayers L.D., *et al.* (eds.), Evolution of Archean Supracrustal Sequences; Geol. Assoc. Can., Spec. Pap. 28, p239-261.

Lewry, J.F. and Collerson K.D. (in press): The Trans-Hudson Orogen: Extent, subdivision and problems; *in* Lewry J.F. and Stauffer M.R. (eds.), The Early Proterozoic Trans-Hudson Orogen of North America; Geol. Assoc. Can., Spec. Pap.

Lord, C.S. (1953): Geological notes on southern District of Keewatin, Northwest Territories; Geol. Surv. Can., Pap. 53-22.

Millar, A.R. (1989): Highlights of gold studies in the Churchill Structural Province, Kaminak greenstone belt and Hurwitz Group, District of Keewatin, N.W.T.; *in* Current Research, Part C, Geol. Surv. Can., Pap. 89-1C, p127-134.

Munday, R.J.C. (1973): The geology of the Dutton Lake area (east half), Saskatchewan; Sask. Dep. Min. Resour., Rep. 155, 22p.

Raman, S., Kruse, J. and Tenney, D. (1986): Geology, geophysics and geochemistry of the Cullaton B-Zone gold deposit, N.W.T., Canada; *in* Clark, L.A. (ed.), Gold in the Western Shield, Can. Inst. Min. Metal., Spec. Vol. 38, p307-321.

Scott, B.P. (1986): Geology of the Phelps Lake (southwest) area, Saskatchewan; Sask. Energy and Mines, Open File Rep. 86-2, 12p.

Taylor, F.C. (1963): Snowbird Lake map-area, District of Mackenzie; Geol. Surv. Can., Mem. 333, 23p.

Tremblay, L.P. (1960): Phelps Lake map-area, Saskatchewan; Geol. Surv. Can., Map 5-1960.

Tyrrell, J.B. (1898): Report on the Doobwant, Kazan, and Ferguson Rivers and the north-west coast of Hudson Bay; Geol. Surv. Can. Ann. Rep., v9, Pt. F, 1898.

Weber, W., Schledewitz, D.C.P., Lamb, C.F. and Thomas, K.A. (1975): Geology of the Kasmere Lake - Whiskey Jack Lake (north half) area (Kasmere Project), Manitoba; Man. Miner. Resour. Div., Geol. Serv. Branch, Publ. 74-2, 163p.

Winkler, H.G.F. (1979): Petrogenesis of Metamorphic Rocks; Fifth Edition, Springer-Verlag, New York, 348p.

Wright, G.M. (1955): Geological notes on central District of Keewatin, Northwest Territories; Geol. Surv. Can., Pap. 55-17.

Bedrock Geological Mapping, Hatle Lake Area (Part of NTS 64M-13 and -14)

B.A. Reilly

Reilly, B.A. (1989): Bedrock geological mapping, Ennadai Domain (part of NTS 64M-13 and -14); *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

The map area is located in the northeastern part of Saskatchewan (NTS 64M-13 and -14), adjacent to the Northwest Territories border, and is centred 160 km northeast of Stony Rapids. Approximately 335 km^2 were mapped at a scale of 1:50,000. Pace and compass traverses were conducted at approximately 0.5 km spacing in the central portion of the map area where bedrock exposure is estimated at 20 percent. Elsewhere, less than 2 percent exposure is found and traverse spacing approximated 1.5 km. A base camp was established at Hatle Lake from August 8 to August 27, during which time mapping was completed.

The map area is predominantly underlain by supracrustal rocks that extend from northeastern Saskatchewan, through the Snowbird Lake area (Taylor 1963), to Rankin Inlet in the Northwest Territories. These rocks form the Ennadai - Rankin (or Rankin - Ennadai) greenstone belt (Wright 1967). Macdonald (1984) coined the term Ennadai Domain for the Saskatchewan portion of the greenstone belt. The Ennadai Domain is chiefly composed of metavolcanic and metasedimentary rocks of the Ennadai Group (Macdonald 1984) and lesser carbonates and calc-silicates which are correlated with the Hurwitz Group. A U-Pb zircon age date of 2682 ± 5.9 Ma obtained from the Ennadai Group (Chiarenzelli and Macdonald 1986) is consistent with Archean ages (2697.5 ± 1.4 Ma and 2692.0 ± 1.0 Ma) recorded by Mortensen and Thorpe (1987) in the Northwest Territories portion of the belt. The Hurwitz Group is of Proterozoic age (Bell 1970a, 1970b). The Ennadai Domain is enveloped by a granitoid-gneiss complex of the Mudjatik Domain. The boundary between the Ennadai Domain and the Mudjatik Domain is ill-defined both to the east and west, and supracrustal rocks may extend further in both directions.

Aspler *et al.* (1989) point out that the term Ennadai Group was used by Eade and Chandler (1975) and Wanless and Eade (1975) for a unit of Proterozoic conglomerate and arkose that unconformably overlies the Hurwitz Group. They proposed a new name, the Kiyuk Group, for this sedimentary unit. The term Ennadai Group is informally used in this report for Archean metavolcanic and metasedimentary rocks of the Ennadai Domain.

Previous work in the area is limited (see Reilly other article this volume). Tyrrell (1898) explored to the west of the Ennadai Domain, along the Wholdaia River system, and to the northeast in the Kasba Lake area. A Federal-Provincial sponsored aeromagnetic survey included the release of aeromagnetic maps for the map area (Geological Survey of Canada 1961a, 1961b). Agarwal (1962) completed a regional correlation of geological and geophysical data, which included the map area. The Ennadai Domain was mapped by Tremblay (1960), part of the Phelps Lake area (NTS 64M), at a 1:253,440 scale.

1. Ennadai Group

a) Mafic to Intermediate Metavolcanic Rocks

Mafic to intermediate metavolcanic rocks (unit Evb) are the dominant rock type in the Ennadai Domain (Figure 1). Both flow rocks and pyroclastic rocks are present, the former being more abundant. Flow rocks vary from massive to pillowed and include local pillow breccia, as well as vesicular, amygdaloidal and plagioclase porphyritic units. Pyroclastic rocks are dominated by tuffs and crystal tuffs which are generally devoid of bedding. Pyroclastic breccia contains fragments which are more felsic in composition than the matrix material. An extensive heterolithic and pyroclastic breccia unit crops out between Lethridge and Frampton Lakes. A monolithic pyroclastic breccia is interlayered with tuffaceous rocks between Tindall Lake and Mackenzie Creek. Epidote pods, comprising less than 5 percent of the rock, occur locally in the mafic to intermediate metavolcanic rocks.

A strongly layered mafic to intermediate (subunit Evbl) rock is located near the southern segment of McLintock Lake. Centimetre-scale layering is defined by alternating mafic-rich (dark green) and mafic-poor (light to medium green) bands. This layering is interpreted as a well-developed tectono-metamorphic layering which obliterates primary textures.

A hornblende-plagioclase gneiss (subunit Evbg) is present proximal to the contact between the greenstone belt and the enveloping granitoid-gneiss complex of the Mudjatik Domain. Alternating hornblende-rich and plagioclase-rich layers are typically millimetre scale and discontinuous in strike length. The hornblende-plagioclase gneiss is predominantly derived from mafic to intermediate metavolcanics. Local amphibolites are associated with the hornblende-plagioclase gneiss.

b) Felsic to Intermediate Metavolcanics Rocks

Felsic to intermediate metavolcanic rocks (unit Eva) are much less voluminous than the mafic to intermediate rocks, and appear to occur interlayered with mafic to intermediate metavolcanic rocks only in the southern and eastern portions of the Ennadai Group (Figure 1). Typically these units are only a few metres thick, except for an area east of Lichfield Lake where a minimum thickness of 400 m is attained. The unit is generally pyroclastic, comprising tuffs or crystal tuffs. A local millimetre-scale gneissosity is present in places where the unit is interlayered with hornblende-plagioclase gneiss. Quartzofeldspathic-rich layers, which comprise greater than 60 percent of the rock, alternate with hornblende-rich layers to define the gneissosity.

c) Clastic Metasedimentary Rocks

Clastic metasedimentary rocks (unit Es) are restricted to the western portion of the map area (Figure 1). Psammitic schist (quartz-feldspar-biotite schist) is the dominant rock type. Sericite is present in more highly strained equivalents. The psammitic schist exhibits no primary structures. Although the contact with the metavolcanic rocks was not observed, the unit possesses a conformable penetrative foliation and metamorphic mineral assemblage of similar grade as the metavolcanic rocks, which suggests that it conformably overlies the metavolcanic rocks.

d) Chemical Metasedimentary Rocks

Chemical metasedimentary rocks (unit Eif) are interlayered with the clastic metasediments and are best exposed southeast of Kanten Lake at the Nirdac Creek gold occurrence (Figure 1). Iron formation consists of predominantly silicate facies and lesser sulphide facies. Individual horizons of iron formation are less than one metre thick. Silicate facies iron formation comprises coarse garnet porphyroblasts within massive to thinly bedded amphibole-rich layers. Chert beds, locally sulphide bearing, and garnetiferous psammitic schist occur in places. Subordinate sulphide facies iron formation, as-

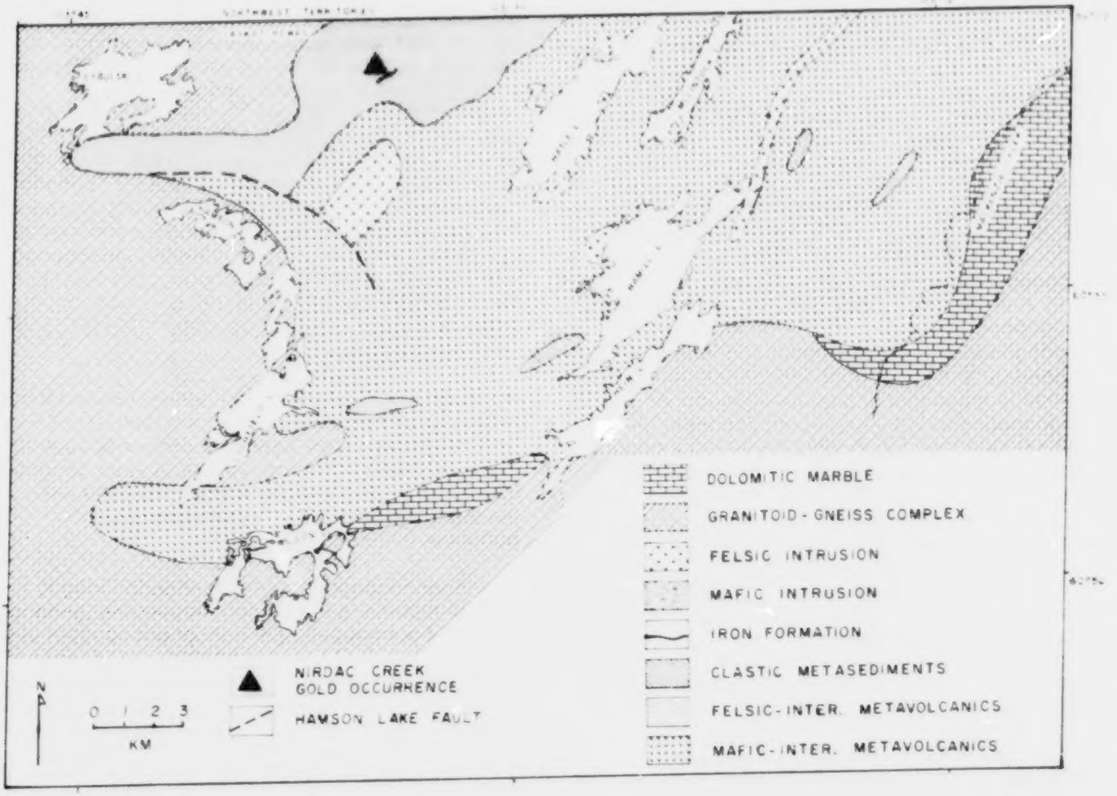

NORTHWEST TERRITORIES
DOLOMITIC MARBLE
GRANITOID-GNEISS COMPLEX
FELSIC INTRUSION
MAFIC INTRUSION
IRON FORMATION
CLASTIC METASEDIMENTS
FELSIC-INTER. METAVOLCANICS
MAFIC-INTER. METAVOLCANICS
NIRDAC CREEK
GOLD OCCURRENCE
HAMSON LAKE FAULT
N
0 1 2 3
KM

Figure 1 – Geological sketch map of the Hatle Lake area.

sociated with the silicate facies, is defined by the presence of pyrite and pyrrhotite.

e) Early Mafic Intrusions

Medium- to coarse- grained gabbroic bodies (unit Eb) intrude the mafic to intermediate metavolcanic rocks. The texture of these rocks is massive, homogeneous and equigranular. Contacts are generally concordant with the stratigraphy and may be sheared, however, where contacts were not observed it is uncertain whether these bodies represent gabbroic intrusions or coarse-grained mafic to intermediate flow centres.

The mafic intrusions possess a metamorphic mineral assemblage and local foliation similar to those in the mafic to intermediate metavolcanic rocks and have been subjected to the same regional metamorphic and deformational event. Field relations suggests that the mafic intrusions may have served as a feeder system to the metavolcanic sequence. Intrusion breccia is present in some of the gabbroic bodies.

f) Early Felsic Intrusions

Feldspar porphyries (unit Egp) crop out in only a few localities within the metavolcanic sequence. They are generally less than one metre thick, exhibit concordant contacts which are typically sheared, and possess a similar metamorphic grade and foliation to the felsic metavolcanic rocks. Like the early mafic intrusions, the feldspar porphyries are interpreted as synvolcanic intrusions.

2. Mudjatik Domain

Enveloping the Ennadai Domain is a granitoid-gneiss complex (unit Mg) which forms part of the Mudjatik Domain. In the map area, this complex is represented by a well-foliated and locally gneissic granitoid complex. Grain size varies from fine to coarse, with quartz and plagioclase porphyritic phases present east of the southern tip of Lichfield Lake. The composition ranges from predominantly granitic to granodioritic-tonalitic.

3. Hurwitz Group

Dolomitic marble (unit Hc), locally interbedded with calc-silicate rocks, crops out along the eastern and southern margins of the Ennadai Domain (Figure 1). The marble is chiefly composed of carbonate (dolomite calcite) and less than 10 percent actinolite/tremolite. Textures are massive, homogeneous and medium grained. Calc-silicate layers consist of centimetre-scale alternating amphibole-rich (hornblende-actinolite-tremolite) and carbonate-rich layers in approximately 60:40 ratio respectively. The calc-silicate layers are medium-bedded and average 30 cm thick within the dolomitic marble. The dolomitic marble and calc-silicate units may be correlated with the similar lithologies mapped in the Hasbala Lake area (Reilly, other article this volume), and are interpreted as belonging to the Proterozoic Hurwitz Group (Bell 1970a, 1970b).

4. Late Felsic Intrusions

The Ennadai Domain is intruded by a series of small felsic bodies (unit Gl) which vary in composition and texture, but are consistently unfoliated. West of McLintock Lake, a long 300 m thick sill-like body intrudes the metavolcanic rocks. Subhedral feldspar phenocrysts, 1 to 2 cm in size, comprise approximately 50 percent of the rock and define a megacrystic texture. Other late felsic intrusions, comprising homogeneous equigranular medium-grained granitoids crop out west of Hamson Lake and on the northwest shore of Hamill Lake (Figure 1). The composition of these granitoids ranges from syenite to granodiorite. These relatively massive undeformed and unmetamorphosed felsic intrusions post-date regional deformation and metamorphism.

5. Diabase Dykes

Steeply dipping diabase dykes (unit Dd) which occur in isolated outcrops are similar in composition and texture to those identified in the Misaw Lake area (Reilly, other article this volume) and are believed to cross-cut all rock units in the map area.

6. Contact Relationships

a) Mudjatik Domain - Ennadai Group

Emplacement of the granitoid-gneiss complex of the Mudjatik Domain has superimposed a contact strain and metamorphic aureole on the supracrustal rocks of the Ennadai Group averaging approximately 1 km and up to 3 km wide. This is manifest in the production of hornblende-plagioclase gneisses, predominantly derived from mafic to intermediate metavolcanic rocks, and quartz-feldspar-hornblende gneisses, originating from felsic to intermediate metavolcanic rocks. The contact zone is also marked by an increase in strain, localized folding, and the development of pegmatitic and aplitic dykes. A chilled margin was mapped within the granitoid-gneiss complex southwest of Hein Lake.

b) Mudjatik Domain - Hurwitz Group

The contact between the Hurwitz Group and the Mudjatik Domain in the map area was not observed but is postulated to be similar to that mapped to the east, i.e. a thrust surface (Reilly, other article this volume). Centimetre-scale layering (gneissosity?) defined by alternating amphibole-rich and carbonate-rich layers in the calc-silicate rocks suggests that the Hurwitz Group was also subjected to the contact strain and metamorphic aureole produced during emplacement of the granitoid-gneiss complex.

c) Hurwitz Group - Ennadai Group

The nature of the contact between the Hurwitz Group and the Ennadai Group is unknown, although it is presumed to be unconformable. The Hurwitz Group does, however, structurally underlie the Ennadai Group, suggesting a tectonic contact.

7. Structural Geology

All supracrustal rocks of the Ennadai Domain exhibit a weak to moderate penetrative foliation which strikes predominantly northeast-southwest. In the western portion of the map area, this foliation dips to the east while in the eastern portion it dips to the west. This structure is interpreted as a regional scale synform (D1) which possesses an axial surface trending through Hatle Lake. A paucity of well-preserved indicators inhibits the identification of the stratigraphic younging direction. The presence of a regional synformal structure within the Ennadai Domain was previously recognized by Tremblay (1960). This interpretation agrees with the regional synform mapped by Taylor (1963) in the Northwest Territories.

Minor-scale folds display predominantly Z-shaped, with lesser W- and S-shaped geometry. Fold axes plunge 10 to 25 degrees to the northeast. Generally, fold amplitude and wavelength are of decimetre scale. An axial planar foliation associated with minor scale folding is predominantly steeply dipping. Although these minor folds may be parasitic to the regional synformal structure (D1), in many localities they have been observed in zones of high strain. Localized low amplitude refolding (D2) is recognized by a change in the dip of the axial planar foliation from steep to subhorizontal.

High strain zones (D3) possess an intensely developed penetrative foliation. These zones are generally strataparallel and concentrated along lithological contacts. Zone widths typically measure a few tens of metres up to a few hundred metres. They transect and deform all rock types. Primary composition and textures are often obscured and obliterated, and a tectonometamorphic banding is present locally. Asymmetric folds and C-S fabric relationships indicate zones of both dextral and sinistral shearing.

A late- to post-tectonic granitoid intrusion, and surrounding supracrustal rocks, is abruptly truncated east of Hamson Lake. In the absence of field evidence this truncation is interpreted as a fault, which is named the Hamson Lake Fault. The geological map pattern suggests chiefly vertical movement along the fault, west-side-up. Faulting of this type is recognized as the last event (D4) in the deformational history of the Ennadai Domain.

Detailed systematic, structural mapping is required to better establish the relationships between multiple folding and possibly multiple shearing events in the map area.

8. Metamorphism

Mafic to intermediate metavolcanic rocks consist of predominantly hornblende and plagioclase. Variable amounts of biotite, epidote, chlorite, and lesser sericite, quartz, potassium feldspar and carbonate are present. Quartz, feldspar with minor sericite and chlorite comprise the felsic to intermediate metavolcanic rocks. Clastic metasedimentary rocks consist of quartz, feldspar, biotite with local sericite. Chemical metasedimentary rocks are garnet and amphibole rich. The mineral assemblages listed above are representative of upper greenschist to low-grade amphibolite facies metamorphism (Winkler 1979). Mineral paragenesis within the Hurwitz Group rocks (Reilly, other article this volume) indicate similar metamorphic grade. Metamorphism of the Ennadai Group and the Hurwitz Group is interpreted as approximately coeval.

Hornblende-feldspar gneisses and quartzofeldspathic-hornblende gneisses, found within the contact strain and metamorphic aureole produced by the granitoid-gneiss complex, indicate an increase in the regional metamorphic grade to medium-grade amphibolite facies metamorphism (Winkler 1979) along the margins of the greenstone belt.

9. Economic Geology

a) Mineral Exploration

In 1969, an airborne radiometric survey was conducted by New Continental Oil Company of Canada Limited (Assessment File 64M13-0002) on the Ennadai - Rankin greenstone belt, including the map area. Minor radiometric anomalies were defined, but no ground followup was attempted.

Saskatchewan Mining Development Corporation (now Cameco) (Assessment File 64M-0004, -0006) acquired two mineral prospecting permits, which encompass most of the Ennadai Domain. Between 1984 and 1986, their exploration program consisted of both regional and grid scale geological and surficial deposit mapping and prospecting, geochemical surveying (bulk till, soil and lake sediment), airborne geophysical surveying (EM and magnetic), ground geophysical surveying (magnetic, VLF-EM and IP/R) and diamond drilling. East West Resource Corporation (Assessment File 64M-0006) carried out geological mapping, prospecting, ground magnetic and EM surveys, as well as diamond drilling on this property in 1987. Athabaska Gold Resources Limited completed prospecting and geological mapping during the summer of 1989 and the property is currently controlled by Cameco (51 percent), East West Resource Corporation (24.5 percent) and Athabaska Gold Resources Limited (24.5 percent). The most significant mineralization found to date, the Nirdac Creek gold occurrence, is hosted by silicate/sulphide facies iron formation.

b) Nirdac Creek Gold Occurrence

The Nirdac Creek gold occurrence is located southeast of Kanten Lake and is hosted within a series of thin horizons of silicate facies iron formation, with subordinate sulphide facies. Gossanous zones are associated with the iron formation and sulphide mineralization consists of pyrite and pyrrhotite. The iron formation is folded, typically Z-shaped, and fold axes plunge shallowly to the northeast. These folds are interpreted as asymmetric shear folds. Shearing within the psammitic schist unit, which is interbedded with the iron formation, is manifest by: 1) an intense penetrative foliation, 2) the development of sericite-rich lenses and layers, which locally comprise up to 10 percent of the rock, and 3) quartz veins which are Z-folded, boudinaged and rotated. Thus, field evidence suggests that the stratabound gold mineralization was remobilized into strata-parallel brittle-ductile shear zones within a broad zone of deformation.

A news release by East West Resource Corporation (1987) recorded one diamond drill hole that intersected a 1.5 m section assaying 0.401 oz. gold per ton. Numerous boulders sampled in the Nirdac Creek area, where two boulder trains meet, also yielded anomalous gold.

c) Exploration Targets

Three favourable environments of mineralization are recognized in the Ennadai Domain. In order of decreasing importance, these are:

1) **Chemical sediment-hosted stratabound gold mineralization which has been subsequently remobilized during shearing :**
Silicate facies, and subordinate sulphide facies, iron formation which hosts the Nirdac Occurrence represent a geological environment similar to that observed in gold mines in the Northwest Territories. The Lupin Mine, situated in the Slave Province, and the Cullaton Lake (B-Zone) mine, a past producer located in the Kaminak Group, are similarly hosted within Archean sedimentary iron formations (Padgham 1984).

2) **High strain zone-hosted gold mineralization:**
High strain zone-hosted gold deposits are not found in any specific rock unit or lithological assemblage, but occur within all rock types in Archean greenstone belts (Colvine *et al.* 1988). Examples of high strain zone-hosted gold deposits located north of the map area include the Con and Giant Mines in the Slave Province. High strain zones in the Ennadai Group host gossans, sulphide mineralization and quartz veins. Although these zones were recognized only in the Ennadai Group, a high strain zone in Hurwitz Group metasediments hosts the Shear Lake gold deposit in the Northwest Territories (Raman *et al.* 1986). These Proterozoic metasediments unconformably overly the Archean Henik Group metasediments which host the Cullaton B-Zone Gold Mine (Raman *et al.* 1986). The proximity of Archean and Proterozoic gold occurrences has led Raman et al. (1986) and Millar (1989) to postulate that Proterozoic gold originally came from buried sources similar to the B-Zone deposit or its parent material or related placer gold accumulations at the unconformity. Consequently, high strain zones serve as favourable sites for gold mineralization irrespective of host lithology and the age of the host lithology.

3) **Volcanic-associated base-metal massive sulphide mineralization:**
Pyroclastic metavolcanic rocks of felsic to intermediate composition are potential hosts for volcanic-associated base-metal massive sulphide mineralization (Franklin *et al.* 1981). Disseminated sulphide mineralization and gossanous zones are present in this rock type within the map area. A mafic to intermediate pyroclastic breccia located between Lethridge and Frampton Lakes possesses a penetrative potassic alteration zone of unknown extent.

10. References

Agarwal, R.G. (1962): Regional Correlation of Geological and Geophysical Data in the Lake Athabasca Area, Northern Saskatchewan; Sask. Dep. Min. Resour., Rep. No. 75, 4p.

Aspler, L.B., Bursey, T.L. and Miller, A.R. (1989): Sedimentology, structure and economic geology of the Poorfish-Windy thrust-fold belt, Ennadai Lake area (65/C), District of Keewatin, and the shelf to foreland transition in the Foreland of Trans-Hudson Orogen; *in* Cur. Res., Part C, Geol. Surv. Can., Pap. 89-1C, p143-156.

Bell, R.T. (1970a): Preliminary notes on the Hurwitz Group, Padlei Map area, Northwest Territories; Geol. Surv. Can., Pap. 69-52, 13p.

Bell, R.T. (1970b): The Hurwitz Group - A prototype for deposition on metastable cratons; *in* Baer, A.J. (ed.), Basins and Geosynclines of the Canadian Shield; Geol. Surv. Can., Pap. 70-40, p159-169.

Chiarenzelli, J.R. and Macdonald, R. (1986): A U-Pb Zircon Date for the Ennadai Group; *in* Summary of Investigations 1986; Sask. Geol. Surv., Sask Energy and Mines, Misc. Rep. 86-4, p112-113.

Colvine, A.C., J.A. Fyon, K.B. Heather, Soussan Marmont, P.M. Smith and D.G. Troop (1988): Archean Lode Gold Deposits in Ontario; Ont. Geol. Surv., Misc. Pap. 139, 136p.

Eade, K.E. and Chandler, F. (1975). Geology of Watterson Lake (west half) map area, District of Keewatin; Geol. Surv. Can., Pap. 74-76, 10p.

East West Resource Corporation (1987): Lupin like geological environment acquired for major exploration follow up diamond drilling planned for twice ore grade assays; News Release, June 29, 1987.

Franklin, J.M., Lydon, J.W. and Sangster, D.F. (1981): Volcanic-Associated Massive Sulphide Deposits; *in* Skinner, B.J. (ed.), Seventy-Fifth Anniversary Volume, Econ. Geol., p485-627.

Geological Survey of Canada (1961a): Geophysics Paper 1259, Wayow Lake, Saskatchewan, Sheet 64 M/13, *by* Can. Aero Service Ltd.

Geological Survey of Canada (1961b): Geophysics Paper 1260, Bailey Lake, Saskatchewan, Sheet 64 M/14, *by* Can. Aero Service Ltd.

Macdonald, R. (1984): Notes on the Ennadai Group; *in* Summary of Investigations 1984; Sask. Geol. Surv., Misc. Rep. 84-4, p76-77.

Millar, A.R. (1989): Highlights of gold studies in the Churchill Structural Province, Kaminak greenstone belt and Hurwitz Group, District of Keewatin, N.W.T.; *in* Cur. Res., Part C, Geol. Surv. Can., Pap. 89-1C, p127-134.

Mortenson, J.K. and Thorpe, R.I. (1987): U-Pb zircon ages of felsic volcanic rocks in the Kaminak Lake area, District of Keewatin; *in* Radiogenic Age and Isotopic Studies, Rep. 1, Geol. Surv. Can., Pap. 87-2, p123-128.

Padgham W.A. (1984): Gold deposits of N.W.T., Classes, Styles, Genesis, Exploration Methods and Success Probabilities; *in* Contributions to the geology of the Northwest Territories, Vol. 1, 1984, I.N.A.C. EGS 1984-6, p121-129.

Raman, S., Kruse, J. and Tenney, D. (1986): Geology, geophysics and geochemistry of the Cullaton B-Zone gold deposit, N.W.T., Canada; *in* Clark, L.A. (ed.), Gold in the Western, Can. Inst. Min. and Metal., Spec. Vol. 38, p307-321.

Taylor, F.C. (1963): Snowbird Lake map-area, District of Mackenzie; Geol. Surv. Can., Mem. 333, 23p.

Tremblay, L.P. (1960): Phelps Lake map-area, Saskatchewan; Geol. Surv. Can., Map 5-1960.

Tyrrell, J.B. (1898): Report on the Doobwant, Kazan, and Ferguson Rivers and the North-West coast of Hudson Bay; Geol. Surv. Can., Annual Rep., Vol. 9, Part F, 1898.

Wanless, R.K. and Eade, K.E. (1975). Geochronology of Archean and Proterozoic rocks in the south District of Keewatin; Can. Jour. of Earth Sciences, vol12, p95-114.

Winkler, H.G.F. (1979): Petrogenesis of Metamorphic Rocks, Fifth Edition; Springer-Verlag, New York, 348p.

Wright, G.M. (1967): Geology of the southeastern barren grounds, parts of the Districts of Mackenzie and Keewatin; Geol. Surv. Can., Mem. 350, 91p.

Bedrock Geological Mapping, Maynard - Wapawekka Lakes Area (Part of NTS 73I-16, 63L-13, 63M-3 and 73P-1)

G.D. Delaney

Delaney, G.D. (1989): Bedrock geological mapping, Maynard - Wapawekka Lakes area (Part of NTS 73I-16, 63L-13, 63M-3 and 73P-1); *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

Revision mapping at 1:20,000 was completed this summer for a 340 km^2 strip between Maynard Lake and the west side of the narrows on Wapawekka Lake (Figure 1). This mapping is a westward extension of remapping completed in the Brownell Lake area by Delaney (1988). Work this past summer focussed on clarifying two main aspects of the geology:

1) The character and extent of economically significant, major shear zones in the Brownell Lake area that trend toward Wapawekka Lake
2) The nature of the tectonic setting in which the supracrustal assemblage in the Wapawekka Lake area was emplaced.

A better understanding of these aspects will lead to an enhanced understanding of the geological history of the southern Glennie Lake Domain as well as aid in developing a model of the geodynamic setting of ore deposits which have formed there.

1. Previous Work

The first documented geological studies are those of McInnes (1913), DeLury (1926) and Worcester (1921). The last-mentioned worker focussed his investigations on the mineral potential of the Wapawekka Lake area. In 1963, Padgham (1966, 1967) mapped the northern halves of the Wapawekka Narrows (73I-16) and Wapawekka Lake (73I-15) map-areas. Also during 1963 Padgham (1968) mapped the Maynard Lake area at a scale of 1:31,680 as part of larger scale 1:63,360 mapping that included map sheets 63L-13, 63L-14(W), and parts of 63L-

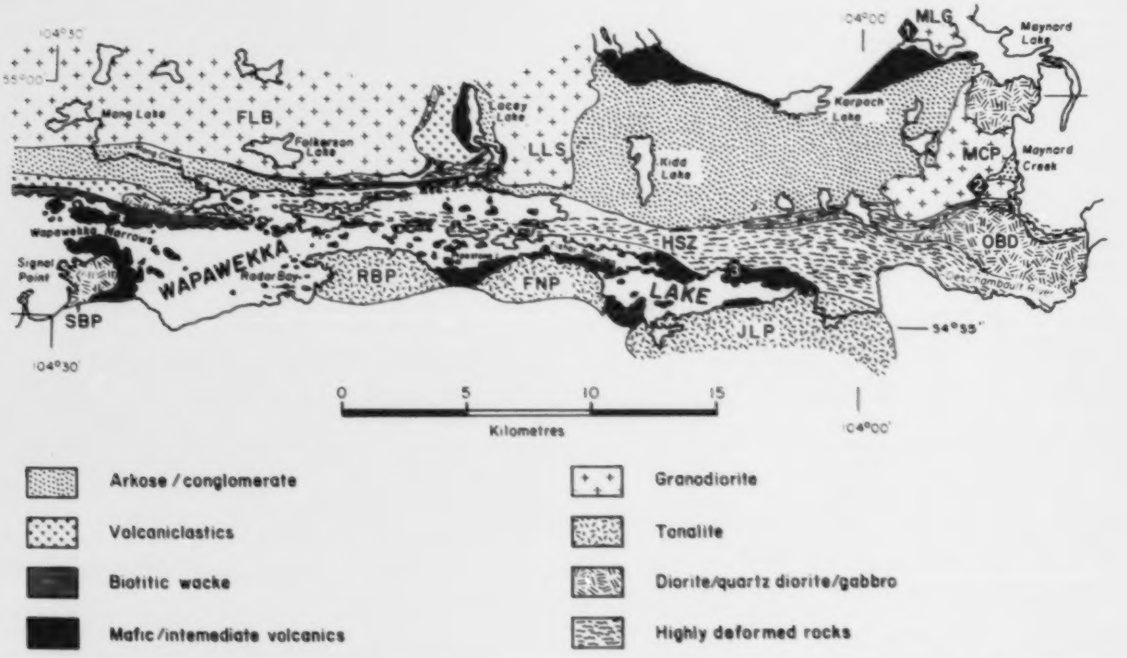

104°30'
55°00'
Meng Lake
FLB
Folkerson Lake
Lacey Lake
LLS
Kidd Lake
Karpach Lake
104°00'
MLG
1
Maynard Lake
MCP
Maynard Creek
2
Wapawekka Narrows
Signal Point
SBP
WAPAWEKKA
Radar Bay
RBP
FNP
HSZ
3
LAKE
OBD
Deschambault River
JLP
54°55'
104°30'
0
5
10
15
Kilometres
104°00'
Arkose / conglomerate
Volcaniclastics
Biotitic wacke
Mafic / intemediate volcanics
Granodiorite
Tonalite
Diorite/quartz diorite/gabbro
Highly deformed rocks

Figure 1 – Geological sketch map of the Wapawekka - Maynard Lakes area. FLB, Folkerson Lake Batholith; FNP, Fisher Narrows Pluton; HSZ, Hartley Shear Zone; JLP, Jura Lake Pluton; LLS, Lacey Lake Stock; MCP, Maynard Creek Pluton; MLG, Maynard Lake Granitoid; OBD, Oskikebuk Quartz Diorite Gneiss; RBP, Radar Bay Pluton; SBP, Signal Bay Pluton. 1, Alex showing; 2, M-10 show-

11 and -12. In 1975 and 1976, Scott (1981) mapped NTS sheets 63M-4 and 63M-3(W) at a scale of 1:63,360. Between 1974 and 1976 Forsythe (1981) mapped NTS sheet 73P-1. The surficial geology of the area south and west of Wapawekka Lake was mapped by Langford (1973).

Most of the map area is included in the 1:250,000 compilation map of the bedrock geology of the Lac La Ronge area (Map 225A; Lewry and Slimmon, 1985). The eastern part of the map area is contained in a similar preliminary compilation map for the Amisk Lake and Pelican Narrows areas (Macdonald, 1981).

An extensive reconnaissance lake sediment geochemical survey by the Geological Survey of Canada in 1974 (Hornbrook *et al.*, 1975, 1977, 1985) covered the present area.

Aeromagnetic coverage is provided by Geological Survey of Canada 1:63,360 scale aeromagnetic maps 4591G (73I-15), 4592G (73I-16), 4593G (63L-13), 4822G (63M-4) and 4821G (73P-1) and 1:250,000 scale aeromagnetic maps 7755G (73I), 7754G (63L), 7764G (63M), and 8190G (73P).

2. Regional Geology

The map area lies in the southernmost exposed part of the Glennie Lake Domain, Trans-Hudson Orogen (Macdonald, 1987). The domain, which is a collage of narrow arcuate belts of supracrustal rocks in granitoids, was interpreted (Lewry, 1981; Lewry *et al.*, 1987; Chiarenzelli *et al.*, 1987) to be the product of the collision with the La Ronge Domain of one or more Lower Proterozoic arc terranes. In order to further refine this model a detailed geological transect of the southern Glennie Lake Domain was commenced in 1988 (Delaney, 1988; Slimmon, 1988; Thomas, 1988). These investigations have enhanced understanding of the structural style and geodynamic evolution of the domain. Lewry and Macdonald (1988, p. 40) in a synthesis of the transect studies noted that "...the southern part of the Glennie Domain appears to comprise a broadly homoclinal north-dipping stack of either predominantly supracrustal or plutonic sheets, typified by inhomogeneous strain and soled in some cases at least, by ductile high-strain zones. Upright cross-folding on predominantly northeast-trending axes modifies this pattern only superficially on the regional scale".

3. General Geology

The basin of Wapawekka Lake is underlain by an east-west-trending and steeply dipping assemblage of supracrustal rocks, the Wapawekka Group, which comprises mafic to intermediate volcanics, volcaniclastics and sedimentary rocks (Figure 1). This greenstone belt is flanked on the north by granodiorites of the Folkerson Lake Batholith and Lacey Lake Stock (Padgham, 1966) and along the southeastern part of the lake by three discrete tonalitic intrusions which from west to east were named (*ibid.*) the Radar Bay, Fisher Narrows and Jira Lake Plutons. To the northeast, rocks of the Wapawekka Group are structurally attenuated against the north-northeast-trending Maynard Creek Anticline which is cored by the composite Maynard Creek Pluton and flanked on the northwest side by the Maynard Lake granitoid. Also in the northeast, to the north of arkoses of the Wapawekka Lake Group, is another succession of volcanic and volcaniclastic rocks. The Maynard Creek Pluton is separated from the structurally tapered Oskikebuk Quartz Diorite Gneiss by the east-west-trending Hartley Shear Zone; a splay of the Hartley Shear Zone also flanks the southern side of the Oskikebuk Quartz Diorite Gneiss. Further to the west the Hartley Shear Zone and other zones of strong deformation dissect supracrustal rocks of the Wapawekka Lake Group.

Two major episodes of deformation have affected these rocks. D1 formed a steeply dipping, east-west-trending foliation, moderate stretching lineation and high strain zones. D2 formed north to northeast-trending folds and an associated ubiquitous fracture cleavage.

Three gold showings have previously been discovered. The most significant of these, the M-10, is associated with heterogeneously sheared diorite along the southern margin of the Maynard Creek Pluton flanking the Hartley Shear Zone.

4. Descriptions of Rock Types

The supracrustal rocks as well as some of the granitoids have been metamorphosed to amphibolite facies. For the purposes of simplicity, however, the prefix meta has been omitted in the following descriptions.

a) Wapawekka Lake Group

Padgham (1966, 1967) named the assemblage of supracrustal rocks in this area the Wapawekka Lake Group, and divided the group into three formations: the Wapawekka Narrows Formation which comprises mostly mafic to intermediate volcanic and volcaniclastic rocks, the Churchman Island Formation which consists mainly of volcaniclastic and sedimentary rocks, and the Wapawekka Lake Formation which is composed of conglomerate and arkose with minor intercalated volcanics.

Wapawekka Narrows Formation:

The Wapawekka Narrows Formation comprises mostly mafic to intermediate volcanic rocks of which a large part is fragmental and a minor part volcaniclastic. Several varieties of volcanics were distinguished during mapping. Many of these varieties are the same as those recognized by Padgham (*op cit*); some are different. Recognition of these varieties is generally restricted to areas of good exposure along the lakeshore.

Flow Rocks – The main varieties of flow rocks distinguished are:

1) Fine-grained, dark green massive to foliated mafic volcanics (WNvb). At many localities these volcanics are amygdaloidal (WNvba).

2) Plagioclase porphyritic mafic to intermediate volcanic rocks (WNvip) characterized by fine- to medium-grained subhedral to euhedral, randomly oriented plagioclase laths.
3) Plagioclase and hornblende porphyritic mafic to intermediate flows (WNvhp).
4) Massive dark green generally medium-grained thick mafic to intermediate volcanic flows or subvolcanic sills (WNvi). Some of these contain rare amygdules.
5) Foliated amphibolite with paper thin to millimetre-thick foliation parallel calcite and plagioclase lenses and layers (WNvbc).

Pillowed flows have only been observed at a few localities. On an island approximately 1.5 km west of Wapawekka Narrows, pillows in a mafic volcanic flow are flattened parallel to foliation. This flow is included in a sequence of volcanic fragmentals and hornblende porphyritic flows. A massive plagioclase porphyritic unit can be traced into a pillowed amygdaloidal plagioclase porphyritic flow on the small islands north of Radar Bay.

Fragmental Rocks – Various types of volcanic fragmentals (unit WNvbo) underlie much of the peninsula south of Wapawekka Narrows as well as the islands to the east and west. Although volumetrically less common than in the Wapawekka Narrows area, volcanic fragmentals are an integral component of the Wapawekka Narrows Formation throughout the map-area. For some of these fragmentals it is still possible to distinguish the process by which they formed. For others, however, post-depositional alteration, metamorphism and deformation mask criteria useful for determining their origin (Parsons, 1969). Many of the fragmentals are interpreted to have been formed in a subaqueous environment and were probably produced by a variety of mechanisms (see Dimroth, 1977).

Compositionally layered hornblende tuff (WNhw) is a minor component in the formation.

Diorite - Gabbro Subvolcanic Sill – East-northeast of Wapawekka Narrows is a narrow six kilometre long body of dark green mesocratic medium- to coarse-grained diorite or gabbro (WNbd1). Near its eastern margin this intrusion is fine grained and locally contains selvage-like features. In the core of the diorite is a 1.5 km long lens of white to pinkish grey fine- to medium-grained leucocratic granodiorite (WNgd). This intrusion is interpreted to be a subvolcanic sill and consequently is included in the Wapawekka Narrows Formation.

A suite of 28 samples of mafic volcanic rock has been submitted for whole rock and selected trace element analyses in order to characterize the tectonic setting of the volcanics.

Churchman Island Formation:

The Churchman Island Formation consists of volcaniclastic and siliciclastic rocks as well as minor intermediate to basic flows and sills and migmatite. Hornblendic volcaniclastics (CIhw), one of the main constituents of the formation, are fine- to medium-grained rocks of variable shades of dark greenish grey with distinct compositional layering defined by differing proportions of hornblende and plagioclase. Clots and lenses of epidote exist locally.

The other main unit in the Churchman Island Formation is a dark grey to buff grey compositionally layered biotitic wacke (CIpl) that is garnetiferous locally. Some exposures of this unit, particularly in the west, contain medium-grained porphyroblasts of plagioclase.

Minor components of the formation are amphibolite (CIm), plagioclase crystal tuff (CIp), quartzofeldspathic gneiss (CIqfn) and diorite gneiss (CIbdn).

At the western margin of the map-area, the north side of Wapawekka Lake is underlain by a narrow strip of quartzofeldspathic migmatite (CIrn). The restite is a light grey weathering and compositionally laminated quartzofeldspathic rock with minor biotite. The leucosome is light buff weathering and strongly foliated plagioclase porphyroblastic quartz feldspar lenses and veins up to 20 cm wide. These veins are generally conformable but locally they bifurcate and cross-cut the layering at a shallow angle. Most commonly the leucosome has a paper thin, even, parallel penetrative foliation.

A small area to the east of the quartzofeldspathic migmatite is underlain by biotite gneiss (CIbn) in which some of the layers host abundant medium- to coarse-grained plagioclase porphyroblasts.

Wapawekka Lake Formation:

The Wapawekka Lake Formation mostly consists of arkose, arkosic grit and conglomerate; hornblende-rich sills and volcaniclastics are a minor component.

Arkose – Arkose (WLr) underlies most of the north shore of Wapawekka Lake and much of the area between the northeast side of Wapawekka Lake and Maynard Lake. Primary structures such as cross-bedding, are only locally preserved, as on the northwest side of the Maynard Creek Anticline. North of Wapawekka Narrows the arkose is more biotitic (WLstp).

Conglomerate – Conglomerate and conglomeratic rocks (WLro) are intercalated in arkose along the north side of Jones Channel and south of Mang Lake. The framework of the conglomerate is polymict pebble-sized clasts. The clasts are mainly arkose, but granitoid and amphibolitic varieties are also present. Deformation of the clasts is variable and in some exposures there has been extreme flattening. For example in conglomeratic lenses south of Mang Lake clasts are only a few millimetres thick but up to 20 cm long when viewed in the plane of foliation.

Quartz grit – Quartz grit (WLrs), which forms part of the Wapawekka Lake Formation near Korpach Lake, consists of granule- and rare pebble-sized quartz clasts forming a disrupted framework in an arkosic matrix.

Deformed rocks – Zones of high deformation dissect rocks of the Wapawekka Lake Formation. In the arkoses flanking Jones Channel mylonites are present. Elsewhere, as along the southern margin of the Folkerson Lake Pluton, near Middlemas Lake, is a very fine-grained grey leucocratic quartzofeldspathic rock (WLrx). In some exposures this unit appears massive but in other places it has a prominent paper thin, even, parallel foliation. Typically, however, this foliation is vague and somewhat masked by granoblastic recrystallization. Local lenses of relatively undeformed thin- to medium-bedded meta-arkose with cross bedding also occur.

Flows, sills and tuffs – Rare mafic flows or sills are intercalated in the Wapawekka Lake Formation. For example the south side of Middlemas Lake is flanked by a coarse-grained hornblendite flow or sill (WLvhp). Along the northern margin of this hornblendite is a fine- to medium-grained amphibolite or amphibolite breccia with abundant centimetre-size amoeboid-shaped calcite lenses. Further to the west, south of Folkerson Lake, hornblendite grades laterally into compositionally layered hornblende tuff (WLvw). Other members of this suite are intercalated in arkose in the area around Kidd Lake.

b) Other Supracrustal Rocks

The northeast part of the map-area, around Korpach Lake, is also underlain by metamorphosed and strongly deformed volcanic and volcaniclastic rocks. Although only a small part of this sequence was mapped these rocks appear to be distinct from the Wapawekka Narrows Formation.

Area west of Maynard Lake:

Two members have been identified:

1) Unit mvw is a compositionally layered sequence consisting of fine-grained dark green amphibole-rich layers and laminations that alternate with light grey plagioclase and plagioclase-quartz-rich laminations. Medium- to coarse-grained porphyroblasts of garnet are scattered throughout the rock or locally concentrated in layers or parallel a strong lineation.
2) Unit mop is a fine-grained dark greenish-grey mesocratic to melanocratic amphibolite with elongated and commonly wispy terminated clasts of plagioclase and various amounts of hornblende. Garnet porphyroblasts are common and in many outcrops plagioclase porphyroblasts occur in both the matrix and clasts. The long axes of these clasts parallel a prominent mineral lineation and rodding.

North of Kidd Lake:

The volcanic sequence here is also divided into two members:

1) The intermediate volcanic member (mvi) is a dark grey fine- to locally medium-grained strongly lineated rock. Some parts of this unit contain hornblende and/or plagioclase porphyroblasts. Rodded pinkish quartz feldspar amygdules were observed rarely.
2) A sequence of metamorphosed and strongly deformed volcanic fragmentals (mop2) is north of the intermediate volcanic member. The unit is texturally variable. Some beds are composed of scattered buff to light grey rodded and wispy-terminated quartzofeldspathic fragments in a fine-grained biotite-hornblende quartzofeldspathic matrix; elsewhere light grey quartzofeldspathic clasts occur in a plagioclase porphyroblastic hornblende-rich matrix. In still other parts plagioclase porphyroblastic fragments are common. Minor garnetiferous semi-pelite is intercalated in this sequence.

c) Intrusive Rocks

Granitoid intrusions occur on both sides of the Wapawekka Lake Greenstone Belt, and core the Maynard Creek anticline in the northeast. A small granitoid body underlies the west side of Maynard Lake. The western tapered tail of the Oskikebuk Diorite underlies the east.

Preliminary petrographic work confirms the observations of Padgham (*op cit*) who noted a distinct polarity in the composition of intrusions flanking the Wapawekka Lake Greenstone Belt. The two intrusions on the north side of the lake are composed of granodiorite. In contrast the three major intrusions on the south side are composed primarily of tonalite and/or quartz diorite. A small basic intrusion is also found on the south side of the lake.

Signal Bay Pluton:

A multiphase basic intrusion underlies Signal Point as well as the islands and much of the peninsula on the northeast side of Signal Bay. Three phases have been mapped, in order of abundance:

1) Dark green, medium- to coarse-grained, mesocratic to melanocratic diorite or gabbro (SLbb),
2) Greenish dark grey, medium-grained mesocratic quartz diorite (SBbd), and
3) Medium-grained, leucocratic to mesocratic, grey to buff dark grey tonalite (SBgt).

The rocks are generally massive; only locally was a foliation or narrow small-scale shear zone observed. Along Signal Bay some outcrops of this intrusion contain fine-grained amphibolitic xenoliths as well as fine-grained plagioclase felsites.

Soapstone:

Soapstone (s) is exposed at five localities on the Pipestone Islands and nearby south shore of Wapawekka Lake; one island on the northeast side of the Wapawekka Narrows is also underlain by a variety of this rock. Typically soapstone is a light greenish grey talc-rich rock which breaks into tabular fragments. Exposures of soft greasy easily carvable "classical" soapstone are rare. The origin of this unit is problematic as noted in the discussion by Padgham (1966). Further geochemical and petrographic studies are required.

Folkerson Lake Batholith:

The Folkerson Lake Batholith forms the northern boundary of an extensive part of the Wapawekka Lake Greenstone Belt. Most of this pluton is a texturally variable, pink to buff, medium- to coarse-grained leucocratic granodiorite (FLgd) that varies from massive to foliated and lineated. A medium-grained mesocratic tonalitic phase (FLgt) is part of the southeast corner of the batholith. Mafic xenoliths, which occur in a few places, vary in size from a few centimetres to several hundreds of metres. Locally the granodiorite is cut by a fine-grained felsite. Along the southern margin of the batholith are narrow mylonitic shear zones showing a dextral sense of movement.

Lacey Lake Stock:

The Lacey Lake Stock (LLgd), lying east of the Folkerson Lake Batholith, is a salmon to pinkish buff medium-grained leucocratic granodiorite characterized by local variations in texture, structure and mineralogy. For example, near the western margin there is a foliated mesocratic hornblende-rich phase. The majority of the intrusion, however, comprises a salmon grey to buff grey, medium-grained leucocratic foliated granodiorite (LLgd). The plagioclase in this variety varies from subhedral to anhedral and is typically coarser than the other constituent minerals. Microcline occurs in fine-grained intergranular clots.

Radar Bay Pluton:

The Radar Bay Pluton, on the south side of Wapawekka Lake consists of two distinct phases:

1) The main phase is a salmon to buff, medium-grained leucocratic tonalite (RBgt) with distinctive smokey blue quartz. This tonalite varies from massive to foliated and locally contains narrow discontinuous ENE-trending shear zones.
2) Dark grey, medium-grained, generally massive, mesocratic quartz diorite (RBbd) is a distinct minor phase in the eastern part of the intrusion.

Fisher Narrows Pluton:

The Fisher Narrows Pluton underlies the south side of Fisher Narrows in the eastern part of Wapawekka Lake. This intrusion is a grey, fine- to medium-grained, massive to foliated, leucocratic tonalite (FNgt) which weathers pink.

Jira Lake Pluton:

The Jira Lake Pluton lies on the southern side of the east end of Wapawekka Lake. The northern margin of this intrusion, the only part mapped, consists of a buff to buff grey, massive to foliated, leucocratic granodiorite to tonalite that weathers with a distinctive granular texture. Plagioclase ranges from 4 to 7 mm in size, is anhedral to subhedral and set in a finer grained matrix of quartz, plagioclase and biotite. Locally the quartz has a distinctive salmon colour. Padgham (1966) noted that the intrusion consists of two other phases besides those described here.

Maynard Creek Pluton:

The Maynard Creek Pluton, on the south side of Maynard Lake, is composed of two distinct phases:

1) The northern part of the intrusion is a buff to pinkish buff medium-grained leucocratic granodiorite (MCgd). Inclusions of grey basic rock are common near the northern margin. The granodiorite is typically foliated and lineated.
2) Diorite to quartz diorite (MCbd) forms the southern part of the Maynard Creek Pluton and consists of two distinct textural varieties. One variety is a medium-grained, mesocratic diorite that is typically massive. The other phase is a diorite to quartz diorite containing scattered medium- to coarse-grained porphyroblasts of hornblende in a fine- to medium-grained groundmass of plagioclase and mafic minerals. These two varieties are intermixed throughout the southern part of the pluton.

Maynard Lake Granitoid:

The Maynard Lake Granitoid underlies the area flanked by the two western arms of Maynard Lake. Only the southern margin of the granitoid was mapped. This rock, which is typically cream-weathering, varies from fine- to medium-grained and is composed almost entirely of quartz and plagioclase with only minor biotite. This intrusion is enigmatic as the ratio of quartz to plagioclase is highly variable over short distances. For example, in one outcrop quartz composes 20 percent of the rock and in an adjacent outcrop it forms 60 percent. Garnet is erratically distributed. The rock is typically cut by plagioclase veinlets which locally contain clotted biotite. Near the narrows of the southwestern arm of Maynard Lake, the granitoid hosts abundant wispy terminated dark grey fine-grained mesocratic xenoliths. A pronounced rodding is common in most exposures.

Oskikebuk Quartz Diorite Gneiss:

The tapered western end of the Oskikebuk Quartz Diorite Gneiss (Padgham, 1966) underlies the southeast. South of Maynard Lake the recognizable part of this granitoid has been structurally thinned to a 100 to 200 m thick "tail" which can be traced another 6.5 km to the west. Quartz diorite gneiss (Obd), the only rock type encountered, is a dark grey leucocratic to mesocratic rock containing medium- to coarse-grained porphyroblasts of plagioclase in a strongly foliated fine-grained matrix of biotite, hornblende, quartz and plagioclase. Narrow shear zones are common near the margins in the wider eastern part of the gneiss and throughout the western "tail" of the granitoid. Highly deformed rocks mantle the Oskikebuk Quartz Diorite Gneiss on both the north and south sides. A few less deformed remnants of the gneiss occur in the thick deformed sequence on the south side of this granitoid.

Pegmatite:

Late stage pink pegmatite (peg) locally cuts both supracrustal and intrusive rocks in the area north of Kidd Lake. The pegmatite is composed of perthitic microcline crystals up to 30 cm long.

d) Rocks in High Strain Zones

Distinct high strain zones dissect the map-area, including:

1) the Hartley Shear Zone, and its probable westward extension is a major shear zone that runs through the centre of the Wapawekka Lake Greenstone Belt; and
2) the area of high deformation along the southern margin of the Folkerson Lake Batholith.

The rocks described in this section have been so deformed that their protoliths are no longer recognizable.

Hartley Shear Zone:

The east-west-trending Hartley Shear Zone (Delaney, 1988) is a major structural break along the northern side of the Oskikebuk Quartz Diorite Gneiss. At the western end of the structurally tapered tail of the gneiss the Hartley Shear Zone merges with another apparently wide but poorly exposed zone of highly deformed rocks along the south side of the gneiss. The strongly deformed rocks of the Hartley Shear Zone and its southern splay are derived from a variety of protoliths. For example, strongly sheared plagioclase porphyroclastic amphibolite along both margins of the Oskikebuk Quartz Diorite Gneiss is interpreted as being derived from this gneiss. Similarly, towards the southern margin of the Maynard Creek Pluton there are east-west-trending narrow shear zones in the diorite; further south in the northern part of the Hartley Shear Zone these are strongly foliated, fine-grained, biotite-hornblende quartzofeldspathic tectonites identical to those in the narrow shear zones. Other varieties of tectonite in the Hartley Shear Zone include: amphibolitic tectonite (mx); dioritic tectonite (bdx) and quartzofeldspathic tectonite (qfx); biotite hornblende tectonite (bhx); plagioclase porphyritic tectonite (pgx).

Biotite-muscovite quartzofeldspathic phyllonite and schist (Clrx) occupies an east-west-trending zone of strong deformation passing through the central part of Wapawekka Lake. These rocks, although somewhat compositionally variable, are typically light greenish grey with subtle compositional laminae, and commonly contain porphyroclasts of plagioclase and more rarely quartz. A fracture cleavage intersects an earlier foliation at a low angle.

5. Structural Geology

A preliminary analysis of the structural data has provided a tentative model of the structural history. Two major episodes of deformation and one minor event are distinguished.

The first event, D1, produced major ductile shear zones and probably folds. A moderate stretching lineation and prominent foliation which generally trends east-west and dips steeply in the Wapawekka Lake area was also produced. Although no folds have been recognized in the Wapawekka Lake area, the D1 deformation, on the basis of structural continuity, is correlated with the second episode of deformation in the Brownell Lake area which formed the overturned Brownell Lake Syncline (Delaney, 1988). D1 also formed major east-west-trending high strain zones including the Hartley Shear Zone and that along the margin of the Folkerson Batholith.

The second major episode of deformation, D2, is manifested throughout the Wapawekka Lake area as a prominent fracture cleavage and locally crenulations or small-scale northeast- to north-trending folds. In the northeast part of the map-area, the D2 deformation modified earlier structures, forming the northeast-trending Maynard Creek Anticline, and probably the large scale north-trending synform which has an axis running through Korpach Lake as well as the small-scale north-trending folds in the vicinity of Kidd Lake.

The final phase of deformation in the Wapawekka Lake area formed narrow brittle east-west-trending faults such as those along the margin of the Folkerson Batholith and on the south side of the major shear zone trending through the centre of Wapawekka Lake.

6. Economic Geology

Although exploration has been carried out for a variety of mineral commodities, including base metals, gold, soapstone and uranium, the only discoveries are three gold showings: Alex, M-10 and Wapa 13.

a) Gold Showings

Alex:

The Alex showing, discovered by regional prospecting in 1986, is a small gossan zone hosted in foliated quartzose granitoid between the two arms on the west side of Maynard Lake. The gossan contains visible clots of pyrrhotite, chalcopyrite and arsenopyrite. Analytical data for a grab sample, 8822-399, from this showing are presented in Table 1.

M-10:

The M-10 showing was discovered in 1988 by Waddy Lake Resources a joint venture partner of Carina Resources the current owner of the property which contains the showing. This discovery was the result of follow-up prospecting, trenching and diamond drilling of a previously known, east-west-trending 700 m long and 460 m wide gold in soil anomaly. The showing is in a heterogeneously sheared diorite near the southern margin of the Maynard Creek pluton (Figure 2). Shear zones in the diorite vary in width from a few millimetres to a few tens of centimetres, and their orientation is generally east-west with a moderate dip to the north.

Table 1 – Geochemical analyses for a suite of grab samples from the Alex showing, Wapa 13 showing and unnamed locality, Wapawekka Lake area. Data for all elements except gold was obtained by ICP analysis of a .500 gram sample digested in nitric aqua regia. For the elements shown in the table, this leach is considered partial for Fe and W. Au analysis is by Atomic Absorption. Analyses by Acme Laboratories.

Samples	Mo (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ag (ppm)	Fe (%)	As (ppm)	K (%)	W (ppm)	Au (ppb)
8822-399	1	7396	42	181	50.3	6.97	118	0.48	1	10215
8922-89	2	49	14	136	0.4	0.91	12	0.1	1	320
8922-329	3	173	3	59	0.1	2	37	0.21	3	30
8922-330	1	300	3	70	0.5	5.5	21	0.77	1	37
8922-331	1	93	7	115	0.1	5.76	7	1.35	1	10
8922-332	3	58	7	21	1.7	1.68	39	0.07	18	260
8922-333	16	216	11	61	1.2	4.18	233	0.72	2231	30
8922-334	26	89	6	38	1	1.64	669	0.06	13	39

Sample Descriptions

	UTM Co-ordinates	Showing	Rock Type
8822-399	6097550N 565670E	Alex	Gossan
8922-89	6091530N 548090E	Unnamed	Quartz vein in felsite
8922-329	6087645N 558750E	Wapa 13	3 cm wide qtz vein in Trench 1
8922-330	6087645N 558750E	Wapa 13	Foliated quartz vein Trench 1
8922-331	6087645N 558750E	Wapa 13	Foliated amphibolite Trench 1
8922-332	6087700N 558970E	Wapa 13	Boudinaged quartz vein Trench 6
8922-333	6087700N 558970E	Wapa 13	1 cm quartz vein in a schistose fragmental

Narrow quartz veins, of more than one generation, which pinch and swell in thickness are aligned both parallel to and at various angles to the shear zones. Some are formed on millimetre-thick shear zones which splay off the main shear at oblique angles. Fine- to medium-grained biotite, feldspar and quartz lenses and veins are also present in the shears. This showing is a few hundred metres north of a flexure in the Hartley Shear Zone. The narrow shear zones that host the showing are of a similar orientation to the Hartley Shear Zone.

During the fall of 1988 four diamond drill holes were completed to test the showing. Additional drilling was carried out in early 1989. Analytical data for three drill holes from the first phase of diamond drilling are reproduced in Table 2. Results of the 1989 drilling have not been released.

Table 2. Analytical data for 1988 diamond drill holes M-10 showing (George Cross News Letter No. 26 (1989) - Feb. 7, 1989).

Hole No.	Intersection	Width	g/t Au
M10-88-2	67.23-69.61 m	2.38m	2.5
incl.	67.23-67.39	.2	18.6
	74.76-75.31	.55	3.5
M10-88-3	11.88-13.41	1.5	1.4
	41.08-42.61	1.53	1.5
	64.70-66.69	1.99	3.7
	82.91-84.00	1.09	3.8
M10-88-4	83.69-85.19	1.50	1.4
	123.29-123.90	.61	5.4

Table 3 contains analytical data for 12 rock samples 8922-470 to 481 collected from some of the trenches which have been dug over the showing. The table also contains analyses of sheared diorite collected elsewhere (Figure 2) along the southern margin of the diorite (8922-373, 1401-02, 1408) and of samples of diorite (8922-1362-63, 1415-16) from other parts of the Maynard Creek Pluton. The latter samples were collected to establish background gold content for the diorite. Comparison of these data indicate the gold content in diorite from outside the southern sheared margin ranges from 3-14 ppb. For samples from within the M-10 mineralized zone some diorite and sheared diorite have gold contents at or slightly in excess of the high end of background values. The highest gold content (2310 ppb) was obtained from a sample (8922-475) of quartz vein hosted in a narrow shear zone in the diorite. The gold content of samples from elsewhere in the sheared southern margin of the Maynard Creek Pluton is generally within background values for diorite although one sample, 373, was slightly anomalous at 38 ppb.

Wapa 13:

The Wapa 13 showing is on the north side of the peninsula on the north shore of Wapawekka Lake approximately 3.4 km from the east end of the lake. Between 1954 and 1965 the showing was held by four different operators who completed a series of trenches (Assessment Files 73I-16-0004, 73I-16-0003, 73I-16-0013, Coombe, 1984). The only assay data reported are those in 1965 by L.A. Lusk who had a grab sample from trench 1 assay 17.8 g/tonne Au and a 18.3 m channel sample from trench 9 assay 4.1 g/tonne Au (Assessment File 73I-16-0014). Later in 1968 Lusk drilled three short holes on behalf of the La Ronge Mineral Syndicate in the vicinity of Trench 1. These holes intersected metavolcanics containing arsenopyrite, pyrite and pyr-

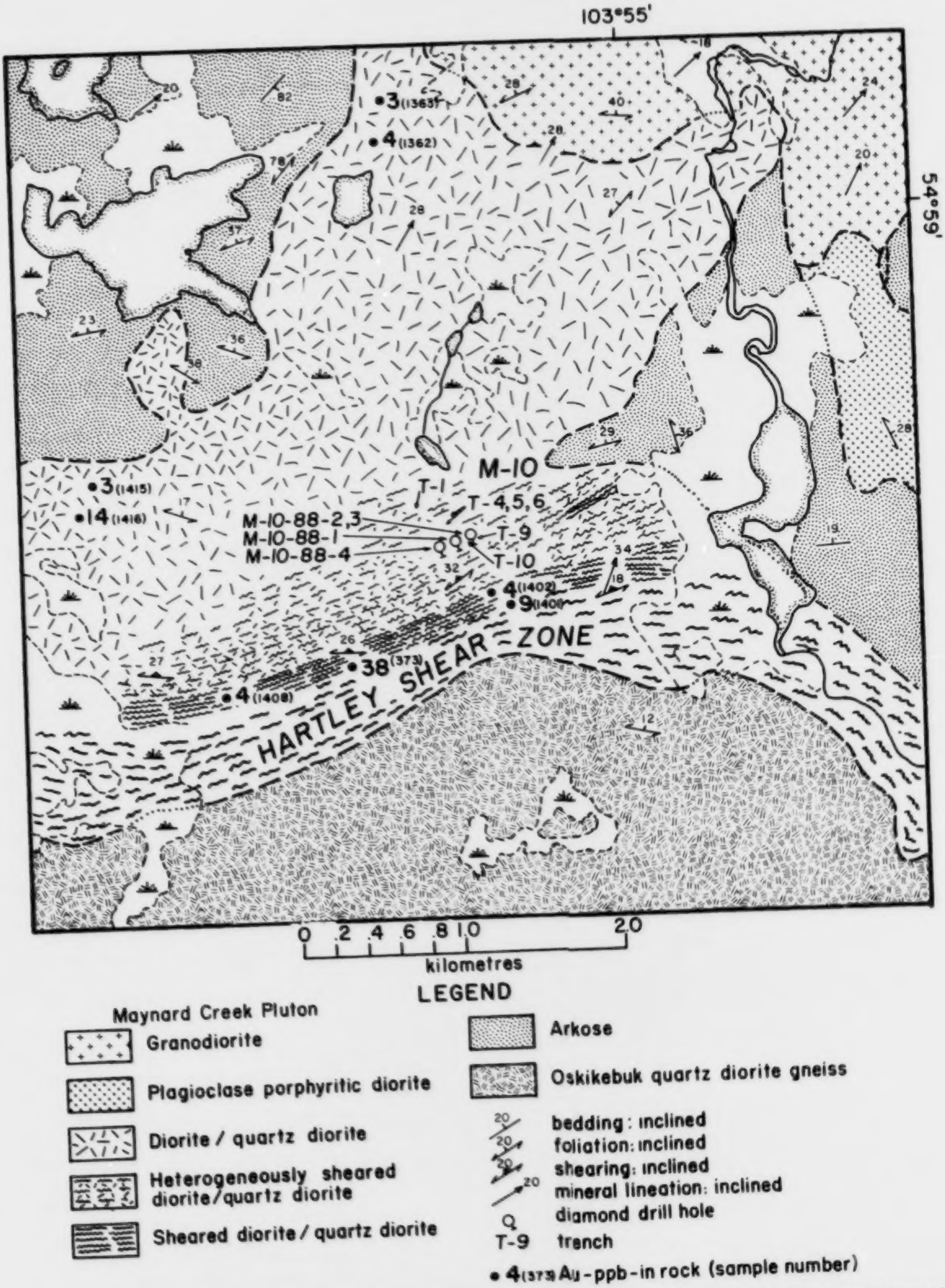

103°55'
54°59'
M-10
T-1
T-4,5,6
M-10-88-2,3
M-10-88-1
M-10-88-4
T-9
T-10
HARTLEY SHEAR ZONE
3 (1363)
4 (1362)
3 (1415)
14 (1416)
4 (1402)
9 (1400)
38 (373)
4 (1408)
0 .2 .4 .6 .8 1.0 2.0
kilometres
LEGEND
Maynard Creek Pluton
Granodiorite
Plagioclase porphyritic diorite
Diorite / quartz diorite
Heterogeneously sheared diorite/quartz diorite
Sheared diorite / quartz diorite
Arkose
Oskikebuk quartz diorite gneiss
bedding: inclined
foliation: inclined
shearing: inclined
mineral lineation: inclined
diamond drill hole
T-9 trench
4 (373) Au-ppb-in rock (sample number)

Figure 2 - Geological setting of the M-10 gold showing. Additional analytical data for rock samples shown on map plus a suite collected from the trenches are presented in Table 3. Analytical data for the diamond drill holes are presented in Table 2.

Table 3 - Geochemical analyses for a suite of grab samples from the M-10 showing and elsewhere in the Maynard Creek Pluton. Data for all elements except gold was obtained by ICP analysis of a .500 gram sample digested in nitric aqua regia. For the elements shown in the table, this leach is considered partial for Fe and W. Au analysis is by Atomic Absorption. Analyses by Acme Laboratories.

Samples	Mo (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ag (ppm)	Fe (%)	As (ppm)	K (%)	W (ppm)	Au (ppb)
8922-470	2	9	3	6	0.3	0.54	3	0.06	1	49
8922-471	3	17	3	5	0.1	0.59	5	0.04	1	14
8922-472	1	33	5	93	0.1	4.45	23	1.44	1	24
8922-473	3	9	4	2	0.1	0.37	2	0.01	1	4
8922-474	1	34	3	112	0.1	3.45	23	1.12	1	5
8922-475	2	58	6	67	0.7	4.11	60	1.24	6	2310
8922-476	2	56	9	54	0.2	2.81	20	0.85	14	18
8922-477	1	53	8	69	0.1	3.96	15	1.02	1	10
8922-478	1	104	2	97	0.2	4.06	42	1.46	1	14
8922-479	2	82	13	104	0.2	4.05	50	1.27	1	16
8922-480	1	23	6	45	0.2	2.28	31	0.69	1	104
8922-481	4	43	2	8	0.1	0.87	83	0.06	1	18
8922-373	1	37	5	85	0.1	3.74	85	1.43	3	38
8922-1401	1	16	7	57	0.4	2.72	2	1.09	1	9
8922-1402	1	42	4	56	0.3	4.04	3	0.46	1	4
8922-1408	1	1	5	81	0.3	3.62	78	1.9	1	4
8922-1415	1	72	2	53	0.4	2.6	2	1.04	1	3
8922-1416	1	54	2	48	0.4	2.53	5	1.09	1	14
8922-1362	2	33	5	65	0.2	3.04	3	1.07	1	4
8922-1363	1	31	5	59	0.1	2.92	8	0.95	1	3

Sample Descriptions

	UTM Co-ordinates	Showing	Rock Type
8922-470	6091580N 567880E	M-10	Subvertical quartz vein 6 cm wide, Trench 1 (14.5 m from south end of trench)
8922-471	6091580N 567880E	M-10	20 cm thick quartz pod, Trench 1 (8 m from south end of trench)
8922-472	6091580N 567880E	M-10	Sheared Maynard Creek Diorite - 14 cm thick shear zone, Trench 1 (5 m from south end of trench)
8922-473	6091580N 567880E	M-10	1 - 10 cm thick qtz vein on splay from main shear, Trench 1, (2m from south end of trench)
8922-474	6091580N 567880E	M-10	Undeformed diorite, hangingwall of shear zone, Trench 1, (1.2 m from south end of trench)
8922-475	6091580N 567880E	M-10	Quartz vein in sheared diorite, main shear, Trench 1 (7.2 m from south end of trench)
8922-476	6091395N 568245E	M-10	Massive undeformed Maynard Creek diorite, Trench 9 (base of trench)
8922-477	6091395N 568245E	M-10	Main shear zone, Trench 9
8922-478	6091260N 568195E	M-10	Hornblende porphyritic diorite, 1.5m below main shear zone, Trench 10
8922-479	6091260N 568195E	M-10	Sheared diorite, main shear zone (25 cm thick), Trench 10
8922-480	6091260N 568195E	M-10	Quartz veinlets in main shear zone, Trench 10
8922-481	6091510N 568075E	M-10	1 cm thick quartz vein aligned vertical to main shear Trench 5
8922-373	6090600N 567440E	None	Sheared Maynard Creex Diorite
8922-1401	6090960N 568457E	None	Sheared Maynard Creek Diorite
8922-1402	6091020N 568320E	None	Sheared Maynard Creek Diorite
8922-1408	6090423N 566640E	None	Sheared Maynard Creek Diorite
8922-1415	6091780N 565760E	None	Maynard Creek Diorite - for background
8922-1416	6091570N 565775E	None	Maynard Creek Diorite - for background
8922-1362	6093850N 567685E	None	Maynard Creek Diorite - for background
8922-1363	6093125N 567738E	None	Maynard Creek Diorite - for background

rhotite but failed to intersect the mineralized quartz vein exposed in Trench 1. In 1972 Hudson Bay Exploration and Development Company completed a horizontal loop EM survey over an extensive area at the east end of Wapawekka Lake that included the area of the showing (Assessment File 73I-16-0019). Although this survey defined an ENE-trending anomaly on the mainland north of the Wapa 13 showing, no response was obtained over the showing itself.

During the summer of 1989 the author visited the Wapa 13 showing and collected a series of grab samples from some of the old trenches (a map in Assessment File 73I-16-0013 shows the trenches referred to in the following discussion) as well as from adjacent recently stripped areas. The data for these samples (8922-329-334) are presented in Table 1. Trench 1 of the Wapa 13 showing exposes a limonitic quartz vein in a strongly foliated amphibolite. Further to the west, in the vicinity of trenches 6-8 is a sequence of pebble-size volcanic fragmentals, lapilli tuffs, bedded tuffs and hornblende schists. There are a variety of quartz veins in the area of the trenches; some are boundinaged, others parallel foliation and are up to 15 cm in width, and a third variety is narrow, folded and contorted, and crosscut foliation at a high angle. A sample of the boudinaged variety, 8922-332, returned 260 ppb Au, the highest gold value for the suite. A sample of the narrow crosscutting veins, 8922-333 has an extremely anomalous W content of 2231 ppm, and this for a sample which was only subjected to a partial acid leach before analysis. Table 1 also illustrates that Ag, As, Cu, Sb, W and Fe are associated with gold in the Wapa 13 showing.

b) Synthesis and Recommendations for Future Prospecting

Detailed remapping by Delaney (1988) defined a major east-west-trending high strain zone, the Hartley Shear Zone, which separates the Brownell Lake Greenstone Belt and the Oskikebuk Quartz Diorite Gneiss. An association was demonstrated between a splay fault from the Hartley Shear Zone and at least one of the gold showings in the Brownell Lake area. During the winter of 1988-89 geological personnel under contract to Waddy Lake Resources applied this interpretation to the discovery and development of the M-10 showing.

The M-10 showing, like the Emco showing at Brownell Lake, is a loci of gold mineralization associated with the major east-west-trending Hartley Shear Zone. In both of the M-10 and Emco, mineralization does not occur in the Hartley Shear Zone proper but in associated shears. The Emco showing lies in a splay fault off of the main shear and the M-10 showing is hosted in heterogeneously sheared diorite about 500 m north of the Hartley Shear Zone.

Mapping this past summer has defined the westward extension of the Hartley Shear Zone as well as other high strain zones in the Wapawekka Lake area including the recognition of a major splay along the southern flank of the Oskikebuk Quartz Diorite Gneiss. Careful evaluation of these high strain zones might lead to the discovery of further gold showings. For example, a grab sample (Table 1; 8922-89) of a quartz vein-bearing felsite from sheared meta-arkose southeast of Middlemas Lake yielded 320 ppb Au.

Recognition of other significant high strain zones might be accomplished by the integration of a variety of techniques:

1) Airphoto and Landsat imagery interpretation,
2) Application of image processing techniques to available Federal Provincial Aeromagnetic data. The successful application of this procedure has already been demonstrated in Ontario (West, 1989),
3) Re-interpretation of existing provincial geological maps. For example Lewry (Lewry and Macdonald, 1988) in re-examining Padgham's (1968) mapping in the Oskikebuk Lake area suggested that much of Padgham's supracrustal assemblage is in fact highly strained rocks which comprise part of a broad heterogeneous deformation zone, and
4) Use of total field and gradiometer surveys over selected areas in particular where exposure is poor.

7. References

Chiarenzelli, J.R., Lewry, J.F., and Landon, M. (1987): Bedrock geology, Iskwatikan Lake area: evidence for Hudsonian juxtaposition of Proterozoic and Archean rocks along a ductile detachment surface; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p46-51.

Coombe, W. (1984): Gold in Saskatchewan; Sask. Energy Mines, Open File Rep. 84-1, 134p.

Delaney, G.D. (1988): Bedrock geological mapping, Brownell Lake area (Part of NTS 63M-4 and 63L-13); *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p8-19.

DeLury, J.S. (1926): Wapawekka and Deschambault Lakes Area, Saskatchewan; Geol. Surv. Can., Summ. Rept. 1924, Pt. B., p23B-50B.

Dimroth, E. (1977): Archean subaqueous volcanic rocks, Rouyn-Noranda area, Quebec: Classification, diagnosis and interpretation: Geol. Surv. Can., Paper 77-1A, p513-522.

Forsythe, L.H. (1981): Geology of the Lac La Ronge - Hunter Bay - Cartier Lake area, Saskatchewan; Sask. Dep. Miner. Resour., Open File Rep. OF 81-1, 20p.

Hornbrook, E.H.W., Garrett, R.G., Lynch, J.J. and Beck, L.S. (1975): Regional lake sediment reconnaissance data, east-central Saskatchewan; Geol. Surv. Can., Open File 266, 108p.

__________ (1977): Regional lake sediment reconnaissance data, east-central Saskatchewan; Geol. Surv. Can., Open File 488.

Hornbrook, E.H.W., Lynch, J.J., Friske, P.W.B., Lund, N.D., and Schmitt, H.R. (1985): Regional lake sediment reconnaissance data, east-central Saskatchewan; Geol. Surv. Can., Open File 1129, 145p (8 maps).

Langford, F.F. (1973): The geology of the Wapawekka Area, Saskatchewan (73I); Sask. Dep. Miner. Resour., Rep. 147, 36p.

Lewry, J.F. (1981): Lower Proterozoic arc-microcontinent collisional tectonics in the western Churchill Province; Nature, v294, no 5836, p69-72.

Lewry, J.F., and Macdonald, R. (1988): Observations on deformation in the Glennie Domain and Hanson Lake Block; *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p35-41.

Lewry, J.F. and Slimmon, W.L. (1985): Compilation bedrock geology, Lac La Ronge, NTS 73P/73I; Sask. Energy Mines, Rep. 225 (1:250,000 scale map with marginal notes).

Lewry, J.F., Thomas, D.J., Macdonald, R., and Chiarenzelli, J. (1987): Structural relations in accreted terranes of the Trans-Hudson Orogen, Saskatchewan: telescoping in a collisional regime (abstract); Geol. Assoc. Can./Mineral. Assoc. Can., Joint Annual Meeting, Saskatoon, May 1987, Prog. Abstr., v12, p67.

Macdonald, R. (1981): Compilation bedrock geology: Pelican Narrows and Amisk Lake areas; 1:250,000 scale prelim. map with Summary of Investigations 1981, Sask. Geol. Surv., Misc. Rep. 81-4.

Macdonald, R. (1987): Update on the Precambrian Geology and Domainal Classification of Northern Saskatchewan; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p87-104.

McInnes, W. (1913): The basins of the Nelson and Churchill River; Geol. Surv. Can., Mem. 30.

Padgham, W.A. (1966): The geology of the Wapawekka Narrows area (North Half), Saskatchewan (73I-16-N); Sask. Dep. Miner. Resour., Rep. 87, 113p.

_________ (1967): The geology of the Wapawekka Lake area (North Half), Saskatchewan (73I-15-N); Sask. Dep. Miner. Resour., Rep. 103, 57p.

_________ (1968): The geology of the Deschambault Lake District comprising the Oskikebuk Lake area, Viney Lake area (West Half), the northern part of the Ballantyne Bay area, and the northeast quarter of the Limestone Lake area, Saskatchewan (63-L-13, 63-L-14-W and parts of 63-L-11, 12); Sask. Dep. Miner. Resour., Rep. 114, 92p.

Parsons, W.H. (1969): Criteria for the recognition of volcanic breccias: a review: *in* Larsen, L., Manson, V. and Priur, M. (eds.), Igneous and Metamorphic Geology; Geol. Soc. Am., Mem. 15, p263-304.

Scott, B.P. (1981): Geology of the Maynard Lake - Sandy Narrows (West) area (NTS Area 63M-4 and 63M-3W); Sask. Miner. Resour., Rep. 186, 26p.

Slimmon, W.L. (1988): Bedrock geological mapping, Gee Lake area (Part of NTS 63M-3 and -4); *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p26-34.

Thomas, D.J. (1988): Bedrock geological mapping, Palf Lake area (Part of NTS 63M-3 and -4 and 63L-13 and -14); *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p20-25.

West, G.F. (1989): Evidence from image processed aeromagnetics on the structure of the Superior Province and the evolution of the Kapuskasing Structural Zone (Abstract); *in* Geol. Assoc. Can., Montreal 1989, Program with Abstracts, v14, pA38.

Worcester, W.G. (1921): Reconnaissance survey of part of northern Saskatchewan; Sask. Dept. Labour and Industries; unpubl. rep.

Bedrock Geological Mapping: Sadler Lake Area (Part of NTS 63M-4 and -5)

W.L. Slimmon

Slimmon, W.L. (1989): Bedrock geological mapping: Sadler Lake area (part of NTS 63M-4 and -5); *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

The Sadler Lake area, located approximately 120 km east-northeast of La Ronge, was geologically remapped this summer at a scale of 1:20,000 (Figure 1). The area covers 170 km^2 and is contiguous with the northwest corner of the previously mapped Gee Lake area (Slimmon, 1988). The following summary outlines the preliminary results determined this summer and a final detailed report comprising both the Sadler Lake and Gee Lake areas will be submitted for an M.Sc. thesis currently in progress at the University of Regina. The Sadler Lake study area was chosen in order to characterize the structure and economic potential, particularly base-metals, of a belt of mixed supracrustal rocks extending northwest from the Gee Lake area and to investigate the possible extension of a ductile high-strain zone that is thought to form the sole of a regionally extensive allochthonous nappe sheet.

Surface topography consists of gently rolling hills with a maximum relief of 60 m interspersed with numerous small lakes which drain into Sadler Lake and north into Trade Lake along the Churchill River system. Precambrian bedrock exposure varies from 20 to 50 percent beneath a thin veneer of mixed Quaternary

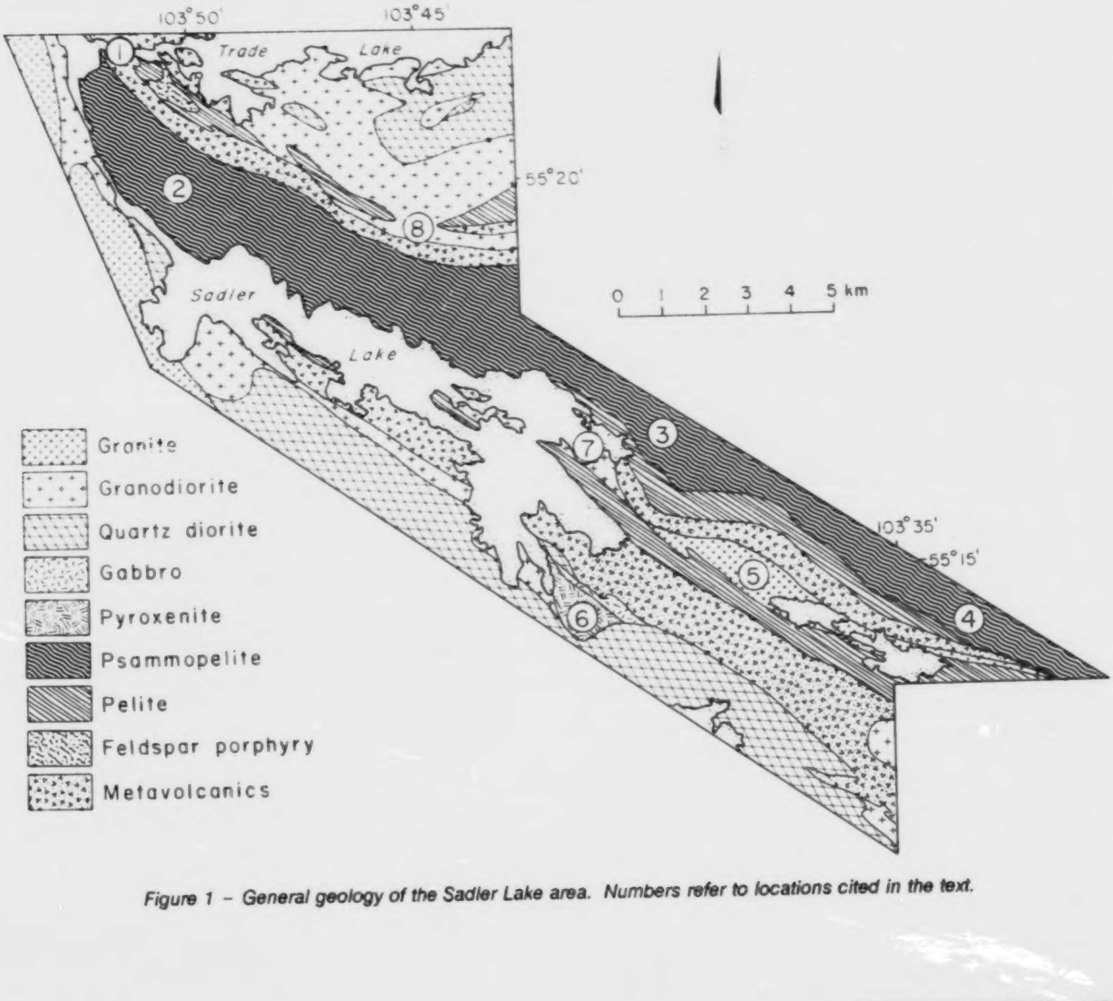

103°50'
103°45'
Trade Lake
55°20'
Sadler Lake
0 1 2 3 4 5 km
103°35'
55°15'
1
2
3
4
5
6
7
8
Granite
Granodiorite
Quartz diorite
Gabbro
Pyroxenite
Psammopelite
Pelite
Feldspar porphyry
Metavolcanics

Figure 1 - General geology of the Sadler Lake area. Numbers refer to locations cited in the text.

glaciolacustrine, glaciofluvial and morainal deposits (Schreiner, 1984). Along the northeast shore and slightly inland of Sadler Lake, exposure decreases significantly to less than 10 percent.

The area comprises parts of previous 1:63,360 scale mapping by Chakrabarti (1968 and 1969) and Scott (1981). Compilation maps covering the area include a 1:254,440 scale map of the Pelican Narrows (NTS 63M) area (Taylor, 1958), and a preliminary 1:250,000 scale map of the Pelican Narrows - Amisk Lake (NTS 63M and 63L) area (Macdonald, 1981). Geological Survey of Canada aeromagnetic maps covering the area include 1:250,000 scale map 7764G (63M) and 1:63,360 scale maps 4822G (63M-4) and 4812G (63M-5). The area is also covered in part by a GSC regional lake sediment geochemical survey (Hornbrook *et al.*, 1975, 1977, 1985).

1. Regional Geology

The Sadler Lake study area is situated in the centre of the Glennie Domain which forms part of the Reindeer Zone, Trans-Hudson Orogen. The Glennie Domain consists of Early Proterozoic granitoid gneisses, plutons and interspersed narrow arcuate supracrustal belts which together are considered to form large refolded nappe sheets soled by ductile high-strain zones (Lewry and Slimmon, 1985; Lewry *et al.*, in press). The map area is located along the boundary between the recently defined Wapassini and Cartier Sheets (Lewry *et al.*, in press). The Wapassini sheet comprises a major allochthonous slice tectonically emplaced southwards over possibly lower crustal rocks of the Cartier Sheet. West of the map area, the Wapassini Sheet is soled by the Guncoat Gneisses, a ductile highly-strained package of mylonitic feldspathoblastic pelites with an upper boundary defined by the Guncoat Thrust (Lewry and Slimmon, 1985).

2. General Geology of the Sadler Lake Area

Approximately 70 percent of the Sadler Lake area is underlain by northwest-striking, northeast-dipping belts of supracrustal rocks comprising metasedimentary to metavolcanic rocks in a 3 to 1 ratio. The metavolcanic rocks consist of about equal amounts of mafic and intermediate rocks with minor interlayered felsic metavolcanics. Southeast of Sadler Lake these rocks comprise part of the Gee Lake Metavolcanic Belt (Slimmon, 1988), which extends another 20 km before terminating east of Gee Lake. Structurally overlying this belt is a thick sequence of metasedimentary rocks extending 15 km northeast of the map area (Chakrabarti, 1969). At the west end of Trade Lake this metasedimentary sequence is structurally overlain by a mixed metavolcanic assemblage of primarily intermediate, subordinate mafic and minor felsic rocks. Northwest of the map area these metavolcanics structurally overlie the Guncoat Thrust (Lewry and Slimmon, 1985).

Intrusive rocks in the area comprise granite, granodiorite/tonalite and quartz diorite mixtures with minor aplite, pegmatite, gabbro and pyroxenite bodies. The structurally lowest rocks in the area comprise part of the Lueder Lake Batholith (Thomas, 1988) in the extreme southwest. The structurally highest rocks occur in the northeast and comprise part of the Wood Lake Batholith (Kirkland, 1976).

3. Metavolcanic Rocks

a) Mafic Metavolcanics (unit Mv)

Mafic metavolcanics are locally interlayered with intermediate metavolcanic rocks, forming the northwest extension of the Gee Lake Metavolcanic Belt (Slimmon, 1988). They are typically fine-grained dark green to black rocks and contain plagioclase, minor quartz and over 35 percent amphibole. Fabrics range from a finely-developed schistosity to near massive fine- to medium-grained amphibolitic varieties. Near massive **amygdaloidal flows (subunit Mva)** frequently occur throughout the belt and contain both feldspar and calcite amygdules averaging 3 mm in diameter. Amygdules are commonly lineated displaying length to width ratios of 10:1. **Pillowed flows (subunit Mvp)** occur in a small zone southwest of Staurolite Lake and in a more extensive belt (0.2 to 0.5 km wide, 3 km long) immediately southeast of Sadler Lake. The commonly amygdaloidal pillows have average diameters of 20 to 30 cm in the YZ plane of the finite strain ellipsoid and lengths up to 150 cm in the XZ plane. Pillow selvages are 2 to 3 cm wide and comprise more mafic fine-grained amphibolitic material with rare garnet segregations. The pillows commonly grade into **pillow breccias (subunit Mvb)** in a southwest direction, which is stratigraphically higher in the sequence as determined by way-up evidence in the pillows.

The mafic metavolcanics along Grand Rapids (1)[1] at the west end of Trade Lake, are fine-grained black amphibolitic flow breccias containing abundant anastomosing calcite veins and cavity fillings. Foliation is often discontinuous and contorted, and a strong L-tectonite fabric is pervasive. Minor amounts of mafic to ultramafic, fine- to medium-grained amphibolitic material occurs here as boudins and disrupted layers less than a metre wide.

b) Intermediate Metavolcanics (unit Iv)

Intermediate metavolcanics are present as local interlayers in the mafic metavolcanics and as discrete belts as much as 700 m wide. They are fine-grained rocks, typically medium to dark grey or green, and contain plagioclase, quartz and 15 to 35 percent mafic minerals including amphibole ± biotite ± garnet. Fabrics include near massive finely laminated and compositionally banded varieties with a pervasive schistosity. Subordinate **volcaniclastic deposits (subunit Ivf)** usually contain abundant lens-shaped felsic clasts that measure 5-10 cm by 0.5-2 cm in the YZ plane and locally up to at least 75 cm in the XZ plane. Highly-strained intermediate ash and crystal tuff beds with transposed layering are common at the west end of Trade Lake. Feldspar-phyric intermediate metavolcanics containing round to subhedral feldspar phenocrysts up to 3 mm in diameter occur in minor amounts southeast of Sadler Lake.

---

(1) Numbers in parentheses refer to locations on Figure 1.

c) Felsic Metavolcanics (unit Fv)

Felsic metavolcanics are sparse in the area and are rarely of mappable size. They commonly occur as finely-laminated or layered ash to crystal tuff beds, a few centimetres to a few metres wide, interlayered with the intermediate metavolcanics. The aphanitic to fine-grained rocks have a crystalline texture and contain less than 15 percent amphibole and biotite. Magnetite and pyrite are commonly associated with the more felsic varieties. Felsic volcaniclastic fragmental deposits are relatively common and contain lensoid felsic clasts averaging 6 cm by 2 cm in the YZ plane.

d) Feldspar Porphyry (unit Fp)

A feldspar porphyry of dacitic composition intrudes the rocks south of Grand Rapids. This light grey rock with 5 to 7 percent biotite and hornblende contains subhedral to round feldspar phenocrysts up to 5 mm in diameter that are typically highly lineated. Elsewhere, feldspar porphyry forms rare sill-like intrusions up to 1 m wide primarily in intermediate metavolcanics.

4. Metasedimentary Rocks

a) Psammopelitic Schist (unit Sp)

Psammopelitic schist occurs along the northeast shore of Sadler Lake in a continuous belt up to 2 km wide. The fine-grained schistose rocks are light brown to grey and chiefly comprise varying amounts of feldspar and quartz. Muscovite averages 5 percent of the rock and locally up to 20 percent, and biotite less than 10 percent. Garnet and sillimanite are rare.

The rocks commonly possess *lit-par-lit* banding due to sharp-walled quartz, leucotonalite and pegmatite injections ranging from a centimetre to several metres wide. North of Sadler Lake (2) the intrusive material commonly comprises 50 percent, and locally up to 100 percent of the outcrops. This percentage decreases to less than 10 percent east of Sadler Lake (3) and to less than 5 percent in the southeast corner of the map area (4). Coarse-grained muscovite-biotite pegmatite is the most commonly injected material and occurs wherever the intrusive layers are present. White- to cream-coloured, medium-grained leucotonalite layers, containing 2 to 3 percent muscovite and less than 5 percent biotite, are restricted to north of Sadler Lake. The quartz layers are typically less than 30 cm wide and are most common in the northwest part of the area along the western boundary of the psammopelite unit. Intrusive layers are generally boudinaged to some degree. North of Sadler Lake several anastomosing high-strain zones produce a protomylonitic admixture of medium- to coarse-grained feldspar and quartz-feldspar porphyroclasts in a fine-grained psammopelitic micaceous matrix.

b) Pelitic Schist (units P and Ps)

Pelitic schists occur in 0.5 to 1 km wide belts parallel and structurally overlying intermediate to mafic metavolcanic rocks in the area. **Garnet-biotite schist (unit P)** is the most abundant pelitic rock and generally contains less than 5 percent idioblastic garnet, (2 to 3 mm in diameter), 10 to 15 percent biotite and locally 5 percent muscovite. These fine-grained brownish-grey rocks are quite homogeneous and possess a strong schistose foliation, but locally they include compositionally banded and finely-laminated varieties.

Staurolite-garnet-biotite schist (unit Ps) occurs in discontinuous zones in the structurally lowest parts of the pelitic schist belts. This unit is very similar in appearance to the garnet-biotite schist with the addition of up to 5 percent idioblastic to subidioblastic staurolite porphyroblasts up to 3 cm long.

c) Meta-arkose (unit Ar)

Meta-arkose underlies a small region in the south corner of the map area where it comprises part of a lens-shaped body extending into the adjoining Gee Lake map area. The cream-coloured rock has a uniformly granular fine-grained texture and is composed primarily of feldspar with minor quartz, less than 5 percent muscovite, less than 3 percent local biotite and traces of garnet. These rocks are distinguished from felsic metavolcanics by their granular texture, low quartz content and the presence of muscovite, as compared to the felsic metavolcanic's crystalline, aphanitic texture, high quartz content and lack of muscovite.

d) Calc-silicate (unit Cs)

Calc-silicate is present in minor quantities and is typically associated with felsic to intermediate metavolcanic rocks either as thin discontinuous boudinaged layers or, more rarely, as outcrop-scale horizons. Fine-grained diopside, epidote and calcite are the main constituents, and the thicker units contain local interlayered chert bands up to 4 cm wide. Pyrite and pyrrhotite occur locally in trace amounts.

5. Intrusive Rocks

a) Pegmatite (unit Peg)

Pegmatite forms *lit-par-lit* layers and small irregular bodies in most rock types. The greatest concentration of pegmatite is in the psammopelitic schists north of Sadler Lake and in the intrusive rocks northwest of Sadler Lake. Muscovite is a common constituent and locally forms books up to 7 cm in length.

b) Granitic Rocks (units G and Gp)

Granite (unit G), which underlies a narrow strip along the western part of the area, is medium-grained, leucocratic, pink to light grey, and contains 25 to 35 percent quartz, 5 to 10 percent biotite, and up to 5 percent local hornblende. Local accessory minerals include epidote, magnetite and pyrite.

Porphyritic granite (unit Gp) forms an elongate lens-shaped body southeast of Sadler Lake (5). The rock is similar to Unit G with the addition of euhedral to subhedral K-feldspar phenocrysts up to 1.5 cm long typically parallel to foliation. Along the northern contact of the porphyritic granite local sill-like layers of granitic material up to two metres wide intrude the metavolcanics.

c) Granodiorite-tonalite (unit Gd)

Granodioritic to tonalitic rocks are the most abundant intrusives in the area. Quartz content averages 25 percent and K-feldspar ranges from less than 5 up to 15 percent. These cream to light grey rocks are medium to locally coarse grained and contain about 15 percent ubiquitous hornblende, 5 percent biotite and traces of epidote, magnetite and rare pyrite. A relatively well-developed, locally gneissic, penetrative foliation increases in intensity adjacent to the supracrustal belts.

d) Quartz diorite (unit Qd)

Quartz diorite is similar in colour, grain size and fabric to Unit Gd and the two rock types are generally intermixed on the outcrop scale and typically separated by gradational boundaries. The rocks contain 5 to 20 percent quartz, 20 percent hornblende, 5 percent biotite, and traces of epidote, magnetite and pyrite.

e) Gabbro (unit Gb)

Gabbro is a minor intrusive, occurring in two lens-shaped bodies; one southeast of Sadler Lake and the other near the northeast limit of the area. The rock is coarse grained, massive to weakly foliated, and contains 50 percent hornblende with minor pyroxene and biotite. Centimetre-scale rhythmic layering is locally present in the gabbros southeast of Sadler Lake.

f) Pyroxenite (unit Pyx)

Pyroxenite primarily occurs as a massive body immediately southeast of Sadler Lake (6). This dark green rock is typically coarse grained with euhedral pyroxene crystals up to 2.5 cm in diameter. Exposures along the lake shore are fine to medium grained, possibly due to shearing. These rocks are highly magnetic and often display a brownish-coloured weathered surface. Traces of pyrite, pyrrhotite and chalcopyrite are present. The pyroxenite intrudes quartz diorite and gabbro country rocks.

Elsewhere in the map area, medium-grained pyroxenite forms isolated outcrop scale exposures in a variety of rock types. Along the east shore of Sadler Lake (7), a mylonitized ultramafic exposure, less than 20 m wide, is thought to have a pyroxenitic protolith. This aphanitic to very fine-grained 'talc schist' is greenish grey on fresh surfaces and weathers light green. The rock has a high talc content and contains local ovoid pyrite blebs 2 to 3 mm in diameter.

6. Structural Geology

Complex polyphase deformation has affected all rocks in the Sadler Lake area. The area comprises a homoclinal northwest-striking, northeast-dipping sequence of supracrustal and plutonic rocks. Primary structures in the metasedimentary rocks have been virtually obliterated during tectonism and metamorphism, but pillow flows, flow breccias, and fragmental structures are locally recognizable in the metavolcanics. Primary layering is also preserved in one gabbroic outcrop southeast of Sadler Lake. A structural sequence of three early ductile deformations (D_1 to D_3) and a late brittle (D_4) deformation has been recognized.

a) D_1 Phase

Primary layering (S_0) in the supracrustal rocks is presumed to be generally parallel to an early schistose foliation (S_1) developed coeval with isoclinal folding during the earliest recognizable deformational event (D_1).

b) D_2 Phase

The D_1 structures are transposed by non-coaxial simple-shear folding (D_2) into parallelism with a strong penetrative schistose foliation (S_2) developed along the axial surfaces of the D_2 recumbent isoclinal folds which have northwest-striking and northeast-dipping axial planes. The S_1 foliation has been essentially obliterated by D_2 deformation and is only rarely visible wrapping around the hinges of the D_1 folds.

D_2 produced a well-developed steeply-plunging north-northeast trending down-dip stretching lineation (L_2) defined by crystal, mineral aggregate and clast elongation and alignment. The lineation is most prominent in the metavolcanic rocks and in the intrusive rocks southwest of Sadler Lake close to their contact with the metavolcanics. D_2 major folds are absent in the map area and D_2 minor folds have been rotated to lie coaxial with L_2.

Anastomosing ductile high-strain zones developed parallel to S_2 during the D_2 deformational event. A strong L_2 linear fabric commonly accompanies the high-strain zones. The zones are most easily distinguished in the plutonic rocks, which developed cataclastic to protomylonitic textures. In the metasediments north of Sadler Lake the zones are defined by the cataclasis of coarse-grained pegmatitic layers which produced a fine- to medium-grained porphyroclastic pegmatite-metasediment admixture, with a strongly schistose micaceous matrix, similar in appearance to a cataclasized plutonic rock. In the metavolcanic rocks the zones are distinguishable where intrusive layers are present, by variable cataclasis and mylonitization, or by highly schistose phyllonitic textures in the metavolcanics themselves.

The most apparent regional-scale high-strain zone occurs north of Sadler Lake along the supracrustal-plutonic rock contact. This zone is 2 to 3 km wide and comprises discontinuous smaller scale anastomosing high-strain zones. Rotated σ_a-type porphyroclasts (Passchier and Simpson, 1986) indicate sinistral movement looking northwest.

More discontinuous high-strain zones occur along the supracrustal-plutonic rock boundary southeast of Sadler Lake and in the metavolcanic belt north of the porphyritic granite intrusion.

c) D_3 Phase

Regional-scale open flexural folding with northeast-trending axial surface traces developed during D_3 deformation. This deformation is manifested by millimetre to centimetre scale crenulation folding with steeply-plunging northeast-trending fold axes most strongly developed in the metasedimentary rocks.

d) D_4 Phase

Late brittle fracturing (D_4) occurs along dominant northeast and, slightly less common northwest trends throughout the map area. Brittle shear zones up to 2 m wide, which typically parallel S_2 foliation, but which formed during D_4, commonly display a dextral sense of movement. Regional-scale faults defined by prominent air-photo lineaments which cross-cut local foliations and lithology contacts have dominant north and northwest trends.

7. Metamorphism

Coexistence of garnet and staurolite in the pelites, and local sillimanite and muscovite in the psammopelites indicates that lower to middle amphibolite facies grades were attained and probably maintained during D_1 to D_3 events. Chloritization along some of the D_4 structures indicates localized retrogression to upper greenschist facies.

8. Exploration Potential

Mineral exploration activity has been relatively limited in the Sadler Lake area and has primarily concentrated on base metals. Presently, parts of several mineral dispositions cover the area north of approximate UTM co-ordinate 6127300mN, as well as a small area in the south corner of the map area which extends from the HBED zone further east (discussed in Slimmon, 1988). In the late Sixties several ground electromagnetic surveys conducted over parts of the area delineated a number of northwest-striking conductive zones. Saskatchewan Energy and Mines assessment files indicate that most of these were investigated by diamond drilling and report several zones of massive pyrite and pyrrhotite with local traces of chalcopyrite. Assays report only traces of copper and zinc. The conductors are primarily associated with metavolcanic rocks, in particular felsic metavolcanics, although one conductive zone north of Sadler Lake (8), centred around UTM co-ordinates 579300mE/6130800mN, coincides with sheared granodioritic rocks.

Most gossans in the area are associated with felsic to intermediate metavolcanics and typically comprise less than 5 percent pyrite with local pyrrhotite and chalcopyrite traces. Grab samples of gossanous metavolcanic rocks from various locations returned copper and zinc values to highs of 218 ppm Cu and 334 ppm Zn[1].

The pyroxenite body southeast of Sadler Lake (6) contains several gossanous zones comprising magnetite and local traces of pyrite, pyrrhotite and chalcopyrite. A grab sample from this area contained 352 ppm Ni and 678 ppm Cr[2]. A grab sample from sheared ultramafic rock at the east shore of Sadler Lake (7) (UTM co-ordinates 5832230mE/6125400mN) contains 351 ppm Ni and 1532 ppm Cr. Both of these areas have slightly elevated platinum and palladium concentrations.

a) Suggested Areas for Further Exploration

(1) More detailed mapping and sampling programs are suggested around gossanous zones in the metavolcanic rocks, particularly in the vicinity of high-strain zones (eg. head of Grand Rapids, UTM co-ordinates 572100mE/6125400mN) and felsic metavolcanic horizons (eg. southeast of Sadler Lake, UTM co-ordinates 584260mE/6124170mN).

(2) Although samples have yet to be analysed from the sheared granodioritic rock coinciding with the EM anomaly noted earlier (8), the area lies along a metavolcanic/intrusive contact and is a possible candidate for a shear-zone hosted mineral deposit.

(3) Further work is warranted in the area underlain by pyroxenite southeast of Sadler Lake (6) and along the structural lineament inland from the sheared ultramafic outcrop on the east side of Sadler Lake (7) to determine the extent of nickel-chromium mineralization and the possibility of PGE mineralization.

9. References

Chakrabarti, A.K. (1968): The geology of the Trade Lake area (west half), Saskatchewan; Sask. Dep. Miner. Resour., Rep. 119, 69p.

______ (1969): The geology of the Trade Lake area (east half), Saskatchewan; Sask. Dep. Miner. Resour., Rep. 134, 31p.

Hornbrook, E.H.W., Garrett, R.G., Lynch, J.J. and Beck, L.S. (1975): Regional lake sediment geochemical reconnaissance data, east-central Saskatchewan (63M, 64D and parts of 73I, O, P and 74A); Geol. Surv. Can., Open File 266 (plus 52 maps at 1:250,000 scale).

---

(1) Geochemical analyses using thirty-element ICP package by ACME Analytical Laboratories, Vancouver.
(2) Partial leach for Cr.

_______ (1977): Regional lake sediment geochemical reconnaissance data, east-central Saskatchewan (NTS 63M, 64D and parts of 63K, L, N, 73I, O, P and 74A); Geol. Surv. Can., Open File 488 (12 maps at 1:250,000 scale).

Hornbrook, E.H.W., Lynch, J.J., Friske, P.W.B., Lund, N.D. and Schmitt, H.R. (1985): Regional lake sediment geochemical reconnaissance data (NTS 63M, 64D and parts of 63K, L, N, 73I, O, P and 74A); Geol. Surv. Can., Open File 1129, 150p (incl. 8 maps at 1:250,000 scale).

Kirkland, S.J.T. (1976): The geology of the Manawan Lake area (south half), Saskatchewan; Sask. Dep. Miner. Resour., Rep. 175, 24p.

Lewry, J.F. and Slimmon, W.L. (1985): Compilation bedrock geology, Lac La Ronge, NTS area 73P/73I; Sask. Energy Mines, Rep. 225 (1:250,000 scale map with marginal notes).

Lewry, J.F., Thomas, D.J., Macdonald, R. and Chiarenzelli, J. (in press): Structural relations in accreted terranes of the Trans-Hudson Orogen, Saskatchewan: telescoping in a collisional regime?; *in* Lewry, J.F. and Stauffer, M.R. (eds.), The Early Proterozoic Trans-Hudson Orogen of North America; Geol. Assoc. Can., Spec. Pap.

Macdonald, R. (1981): Compilation bedrock geology: Pelican Narrows and Amisk Lake areas; 1:250,000 scale prelim. map *with* Summary of Investigations 1981, Saskatchewan Geological Survey; Sask. Miner. Resour., Misc. Rep. 81-4.

Passchier, C.W. and Simpson, C. (1986): Porphyroclast systems as kinematic indicators; J. Struc. Geol., v8, p831-843.

Schreiner, B.T. (1984): Quaternary geology of the Pelican Narrows area (NTS 63M, N); Sask. Energy Mines, Open File Rep. 84-3 (1:250,000 scale map with marginal notes).

Scott, B.P. (1981): Geology of the Maynard Lake - Sandy Narrows (west) area; Sask. Miner. Resour., Rep. 186, 26p.

Slimmon, W.L. (1988): Bedrock geological mapping, Gee Lake area (part of NTS 63M-3 and -4); *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Sask. Energy Mines, Misc. Rep. 88-4, p26-31.

Taylor, F.C. (1958): Pelican Narrows, Saskatchewan; Geol. Surv. Can., Map 1-1958 (1:253,440 scale map with marginal notes).

Thomas, D.J. (1988): Bedrock geological mapping, Palf Lake area (part of NTS 63M-3 and -4 and 63L-13 and -14); *in* Summary of Investigations 1988, Saskatchewan Geological Survey; Sask. Energy Mines, Misc. Rep. 88-4, p20-25.

Glennie-Kisseynew P-T Study 1989: Fieldwork and Preliminary Results

Dexter Perkins

Perkins, D. (1989): Glennie - Kisseynew P-T study 1989: Fieldwork and preliminary results; *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

This project is a continuation of the one started during the summer of 1988. The project is a joint venture undertaken by the University of North Dakota and Saskatchewan Energy and Mines. The goal of the project is to determine the nature and variation of metamorphic temperature and pressure recorded by rocks from the Pelican Narrows area, northeastern Saskatchewan. After two years, most of the necessary fieldwork has been completed. Thin sections of key samples have been prepared, and chemical analyses are being obtained. There is still, however, much laboratory and interpretive work remaining to be done.

During August, 1989, a four man field crew spent two and a half weeks sampling rocks from a 2500 km^2 area in the southeastern part of the Saskatchewan Shield. Access was almost entirely by aircraft. Multi-day base camps were set up on some of the large lakes east of Pelican Narrows. Over 600 samples were collected, of which about one third have been prepared as thin sections. Analysis of minerals in the sections, and application of mineralogical thermometers/barometers will take place during the winter 1989-90.

1. Sampling

The area of investigation has been described previously (Perkins, 1988). The northern border coincides with the Churchill River system, the southern with the Hanson Lake Road. In the west, samples were collected on Trade, Sadler and Brownell Lakes. In the east, sampling was conducted on Kipahigan and Chicken Lakes. Many lakes have been sampled in between.

Fieldwork during 1989 was mostly in the eastern half of the area. Except for a few outcrops, mostly on the road between Sandy Bay and Pelican Narrows, all sampling was done by fly-in to major lakes. West of the Tabbernor Fault, the geology at Lindstrom and Deschambault Lakes was examined. North of Pelican Narrows, the larger lakes visited and sampled included Pikusikun, Ukoop, Chachukew, Maguire, and Marchel. Sokatisewin, Wasawakasik, Okipwatsikew, Chekuhikun and Kipahigan Lakes were sampled in the Sandy Bay region and farther south, Mari, Wildnest, Golden, Phelan, Nemei, Belcher, Mukhoman, and Ohoo were sampled. A two-day trip through the Attitti Block area produced no rocks appropriate for this study. Some sampling was also done via access from the Hanson Lake Road between Jan Lake and Flin Flon.

All the areas sampled have received attention from geologists in the past. The basic geology is well summarized by Macdonald (1981). References are summarized by Perkins (1988) and Macdonald (1981). The samples collected during this study were mostly those that appeared to contain key metamorphic mineral assemblages, or that appeared to be suitable for application of quantitative geothermometers and geobarometers. In particular, rocks were sampled if they contained andalusite, kyanite, sillimanite, garnet or cordierite. Multiple samples were taken if two or more of these aluminous minerals were present. In addition, samples of biotite-bearing metasediments and hornblende-bearing metabasites were collected even if the other minerals were absent.

2. Distribution of Al_2SiO_5 Minerals

It is well known that the aluminosilicate minerals andalusite, kyanite and sillimanite are good general indicators of metamorphic pressure and temperature (Thompson, 1976; Winkler, 1979; Holdaway, 1971). Sillimanite is the high temperature polymorph and kyanite the low temperature/high pressure polymorph. Andalusite is stable in a restricted field of pressure-temperature space below 4 kbar.

After two years of fieldwork, the distribution of sillimanite and kyanite in the field area is clear. Most of the aluminous rocks across the entire region contain sillimanite - in places as discrete grains and elsewhere as fibrolite inclusions in cordierite. In the southeastern part of the field area, sillimanite is absent. Kyanite has been found at Mari, Little Mari and Cotteral Lakes. Preliminary results suggest that the rocks in the southeast are lower temperature than those elsewhere in the region.

Few samples of andalusite have been found. Samples from the eastern end of Deschambault Lake and from near Piney Lake may suggest a low pressure metamorphic regime. There are, however, other rocks nearby that contain abundant amounts of sillimanite. One other location, near Wood Lake, also contains andalusite. All three samples were collected adjacent to the Tabbernor Fault. The presence of the andalusite-bearing rocks may be due to tectonic emplacement or hydrothermal activity associated with the fault and associated shears. Closer scrutiny to structural relationships in outcrop, and perhaps more detailed mapping are needed to clarify the problem.

3. Granulite Facies Rocks

Kirkland (1976) reported the occurrence of orthopyroxene in several locations northeast of Pelican Narrows. Several forays were made into those areas, but no orthopyroxene was found. To date, the only true granulite facies rocks (Winkler, 1979) that we have found are from the Sahli Dome and from units mapped as enderbite by Macdonald (1981) near Chicken Lake. The rocks at Chicken Lake are most intriguing and bear little resemblance to any found elsewhere in the region. They appear to be coarse-grained plutonic units containing dominantly quartz, plagioclase and orthopyroxene. They are intimately associated with garnet-cordierite metasediments and in many places the two rock types grade from one to the other.

In many other areas there are signs of high temperature, such as large quantities of diatexite or metatexite, or spinel-quartz assemblages, but orthopyroxene is absent. This may, in part, be due to the highly potassic and aluminous composition of most of the Kisseynew Gneiss and related rocks that dominate the area. Such rocks tend to melt at temperatures below those at which orthopyroxene may form.

4. Geothermometry

Semiquantitative analyses of garnet, biotite, cordierite and muscovite have been obtained from about 75 thin sections. Quantitative analyses are now being collected (Figure 1). Based upon the analyses completed, the garnet-cordierite and garnet-biotite geothermometers of Perchuk and Lavrent'eva (1983) have been applied. The results show that over most of the study region, metamorphic temperature was between 630° and 680°C. To the west of the Tabbernor Fault, the temperatures indicated are 50°-100°C lower, and near Mari and Wildnest Lakes temperatures of about 600°-630°C were determined. During the last field season, no thermal halo was found around the Sahli Gneiss, which is consistent with the gneiss being a window of underlying Archean basement. In contrast, the rocks near the orthopyroxene-bearing units at Chicken Lake appear to be higher temperature than those farther south and west.

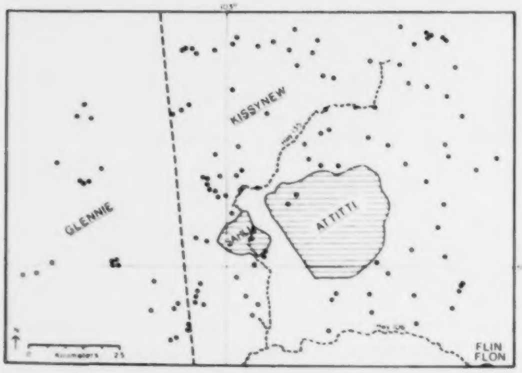


Figure 1 – Map of the area under investigation. Dots show locations of samples for which mineral analyses are being obtained. Names of some of the important geological domains are shown. Large dashed line is the trace of the Tabbernor Fault; fine dashed lines are roads. Attitt = Attitti Block, Sahli = Sahli Granite.

5. Continuing Investigations

After two years of fieldwork, most of the key areas have been sampled in this broad regional survey. The emphasis in the project will now shift to obtaining mineral analyses. It is anticipated that only brief forays into the field will be required to complete this project. During the 1990 calender year, while the principal investigator is on sabbatical leave, mineral analyses will be collected which should bring this project close to an end.

6. References

Holdaway, M.J. (1971): Stability of andalusite and the aluminum silicate phase diagram; Am. J. Sci., v271, p97-131.

Kirkland, S.J.T. (1976): The geology of the Marchel - Wintego - Sandy Bay area, Saskatchewan; Sask. Dep. Miner. Resour., Rep 172, 12p.

Macdonald, R. (1981): Compilation bedrock geology: Pelican Narrows and Amisk Lake areas; *in* Summary of Investigations 1981, Sask. Geol. Surv., Sask. Miner. Resour., Misc. Rep. 81-4, p16-23.

Perchuk, L.L. and Lavrent'eva, I.V. (1983): Experimental investigation of exchange equilibria in the system cordierite-garnet-biotite; *in* Saxena, S.K. (ed.), Kinetics and Equilibrium in Mineral Reactions, Springer, p199-239.

Perkins, D. (1988): Glennie-Kisseynew P-T study 1988: fieldwork and preliminary results; *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep 88-4, p32-33.

Thompson, A.B. (1976): Mineral reactions in pelitic rocks: I. Prediction of P-T-X(Fe-Mg) phase relations; Am. J. Sci., v276, p401-454.

Winkler, H.G.F. (1979): Petrogenesis of Metamorphic Rocks; Springer-Verlag, 348p.

Structural Controls on Gold Deposits in the La Ronge Domain, Saskatchewan: A Progress Report

R.G. Roberts[1] and P.L. Schwann

Roberts, R.G. and Schwann, P.L. (1989): Structural controls on gold deposits in the La Ronge Domain, Saskatchewan: A progress report; *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

Detailed investigation of controls on gold mineralization in the northern part of the La Ronge Domain, in particular the deposits of the Star Lake and Island Lake Plutons, was undertaken this summer. Previous investigations (Poulsen, 1985, 1986a,b, 1987) provide useful summaries of the concepts of structural geology as applied to ore genesis in this region.

1. Star Lake and Island Lake Plutons

The geology of the Star Lake Pluton is described by Poulsen *et al.* (1986a,b) and Thomas (1985). The pluton covers an area of approximately 14 km^2, and is elliptical in plan, with the longer axis trending north-northeast. The igneous rocks of the pluton are coarse to medium grained, with a zonation from dioritic rocks at the margin, through quartz monzonite to a granitic core. The Island Lake Pluton has an areal extent of 24 km^2, and is south of, and in faulted contact with, the Star Lake Pluton. Thomas (1985) describes the pluton as being of comparatively uniform composition, typically biotite leucogranite, but with minor monzonite to quartz monzodiorite.

a) Structural Geology

Most of the structural data in this report are from the Star Lake Pluton. There are two principal aspects to the structural geology of the pluton: 1) the regional fabric of the pluton (the S1 foliation of Poulsen *et al.*, 1986b) and associated lineation and 2) the shear zones that host the gold deposits.

Regional fabric (S foliation):

The foliation varies in intensity from weak to moderately strong. It is defined by the preferred orientation of biotite (after hornblende), and to a lesser extent by lens-shaped feldspar grains and aggregates. Within the foliation, the long axes of aggregates of biotite grains define a lineation that plunges down dip. Consequently, and particularly where strain is weak, the lineation-foliation fabric may be difficult to see on horizontal surfaces, but is quite obvious on vertical surfaces.

Foliations with the above characteristics typically occur with at least two distinct attitudes. Thus the attitude of the foliation may change across an outcrop, or the two attitudes may be represented by cross-cutting foliations in which one direction is dominant (Figure 1). In either case it is generally not possible to determine the age relationships of the foliations. The intensity of the foliation may increase to form localized zones of high strain, up to 10 cm wide and with strike lengths up to 2 m. C-S fabrics present in some of the local high strain zones indicate that the strain is rotational, and provide information on the sense of slip (Figures 2 and 3).

A further characteristic of the deformation associated with the S1 foliation, is the local development of tabular zones of fine-grained cataclastic material (Figure 3). The zones, typically up to 3 cm wide and 30 cm long, form discrete entities parallel or subparallel to the foliation. Occurring rarely, 0.5 m wide bands of interlayered cataclastic material and foliated rock.

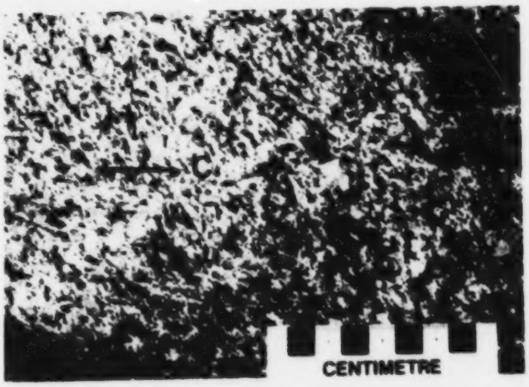


Figure 1 - The photograph illustrates the nature of the foliation in the Star Lake Pluton. The dominant foliation (A) strikes between 020° and 035° and dips steeply northwest. Foliation (B) strikes between 055° and 060° and dips steeply northwest. Foliation (C) strikes 180° to 185° and dips steeply east.

The field data on the S1 foliation and the data from oriented specimens has not yet been completely analysed. The approximate attitudes of the foliation groups that have been identified thus far are as follows: (1) strike 020°, dip 60° NW; (2) strike 050°, dip 75° NW; (3) strike 164°, dip 80° E. The minor shear structures as-

---

[1] Department of Earth Sciences, University of Waterloo, Waterloo, Ontario

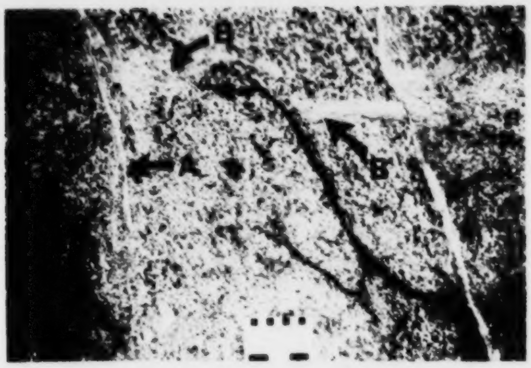


Figure 2 - Star Lake Pluton The small dextral shear (A) strikes 040° and dips northwest at 65°. The shear at (B) trending 150° is sinistral. Both structures contain quartz feldspar vein material. Foliation is approximately parallel to shear (A).

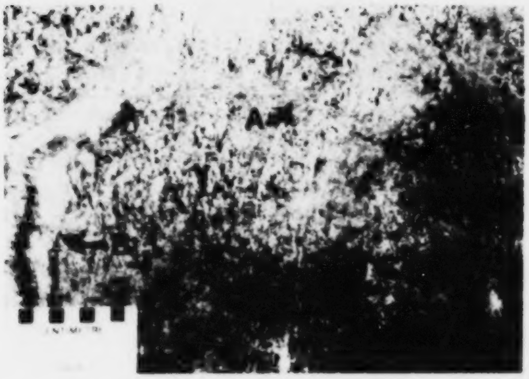


Figure 3 - Star Lake Pluton; diorite The photograph illustrates a narrow shear at (A) (strike: 052°; dip: 60° NW), which displaces a sinistral shear (B) (strike: 162°; dip: 50°). The (B) shear contains quartz feldspar vein material. (C) is cataclastic material in a tabular body, subparallel to (B). The dominant foliation is parallel to the shear direction of (B).

sociated with foliation directions (1) and (2) are dextral, and those with foliations (3) and (4) are sinistral.

Shear Zones and Gold Mineralization:

Gold mineralization in the Star Lake Pluton has been shown by Poulsen *et al.* (1986b) to be related to ductile mylonitic shear zones that typically strike at 060° degrees and dip steeply northwest. The shear zones are up to 30 m wide and at least one shear (the Star Lake Shear) has been traced completely across the pluton. Seven shears have been identified, six of which host gold mineralization. The Star Lake mine closed down in 1989, and presently the Jolu mine is the only producer.

The shear zones contain the same lineation that is associated with regional deformation, but it is more strongly developed. The lineation occurs at the intersections of foliations in the shear zone, and is parallel to the axes of folded, narrow aplite dykes in the shear zone. Figure 4 is a stereographic plot of poles to the foliations and shear planes in a section of the Rod Shear, exposed for a strike length of 65 m, approximately 1 km northeast of the Jolu mine. The poles provide an estimate of the line of intersection of the planar structures. The line of intersection plunges steeply north-northeast. The direction of shearing is subhorizontal and perpendicular to the lineation defined by the biotite and aggregates of biotite grains. The sense of movement is dextral, as noted by Poulsen *et al.* (1986b).

Quartz veins are associated with the shearing described above, and these may be expected to plunge steeply, approximately parallel to the line of intersection of the shear planes and foliations.

The Jolu orebody is a gold-bearing quartz vein deposit in the Rod Shear and in the Rod South Shear which is a splay to the main shear. The veins are confined to the shear zone and have the attitude of P-shears within the narrow shear zone. At the mine, the dip of the northeast-trending shear zone is reversed, and the shear dips subvertically to the southeast. The Jolu orebody plunges to the southwest at 60° which coincides with the plunge of the line of intersection of the Rod Shear with the Rod South Shear, as well as the plunge of minor fold axes within the ore-bearing section of the shear zone (Figures 5 and 6). Thus the direction of shear movement associated with the emplacement of veins at the Jolu mine

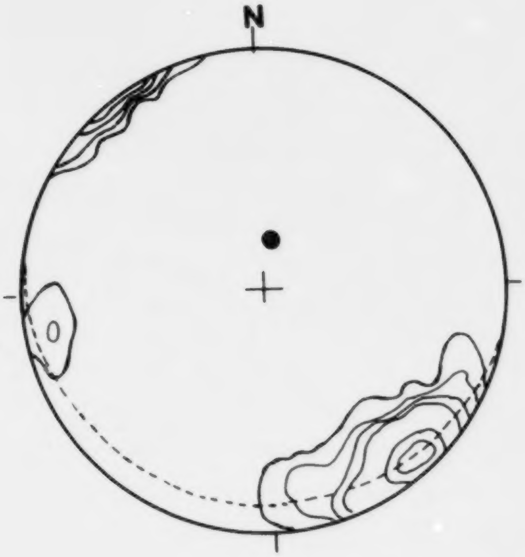


Figure 4 - A stereographic plot of poles to foliations and shears taken from the Rod Shear, approximately 1 km northeast of the Jolu Mine. The poles to the planar structures lie on a great circle; the pole to this great circle plunges steeply north-northeast and approximates the line of intersection of the planar structures. (60 points; contour interval: 4% per 1% area).

plunges at 80° NE in the plane of the shear. The sense of movement is dextral, the northwest side of the shear moving down relative to the southeast side.

In summary, the Rod Shear zone is dextral, with the direction of slip being subhorizontal (plunging at approximately 10° SW, but at the Jolu mine, emplacement of the quartz veins is associated with later dextral slip, probably confined to the central part of the shear, in a direction which plunges northeast at 30°. The younger, vein-bearing strain regime, is enclosed in the older strain regime.

2. Island Lake Pluton

Data on the attitude of the fabrics of the Island Lake Pluton were not collected, but it was noted that the form of the foliations, and in particular the occurrence of an associated, subvertical lineation, suggests that the deformation is comparable with that of the Star Lake Pluton. Several showings of shear zone hosted gold deposits have been discovered, of which the most significant is the Jasper deposit, where exploration has advanced to the stage of underground development. At surface, the Jasper orebody is a layered, pyritic, cherty quartz vein system, occupying a ductile shear that strikes approximately 035° with a vertical or steep northwesterly dip. The deposit consists of a number of discrete linear orebodies each raking, within the shear zone, at approximately 80° from the northeast. The map (in pocket) covers the southwest limit of the deposit, as its dimensions are presently understood, and the southwestward continuation of the shear zone and its associated vein system which form the James deposit. The shear zone consists of a system of branching, smaller shears in which the principal vein-hosting shears

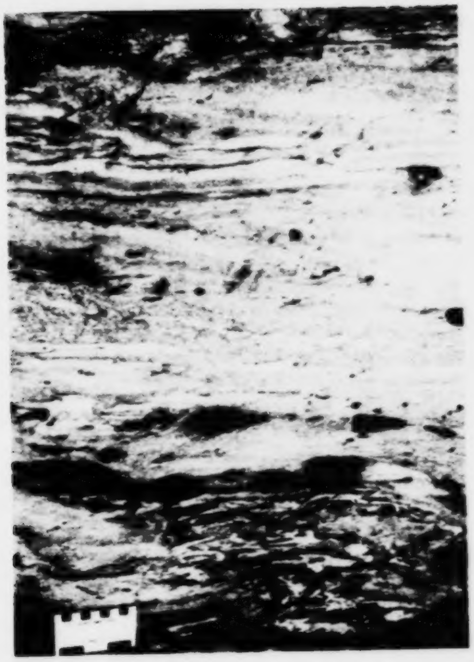


Figure 5 – The Rod Shear at the Jolu mine. The minor folds in narrow aplite dykes plunge 60° southwest.

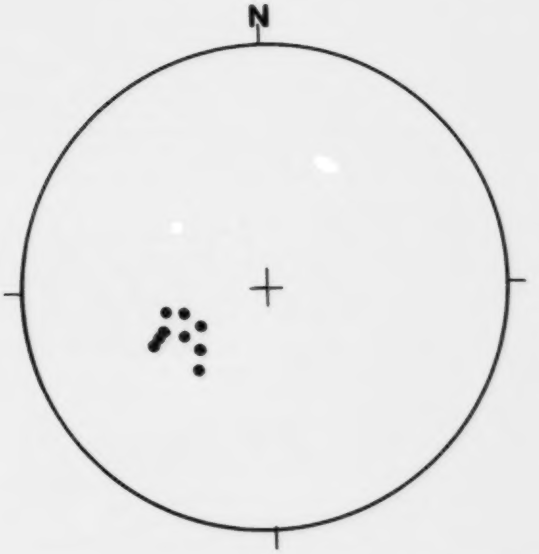


Figure 6 – Stereographic plot of axes to the minor folds shown in Figure 5.

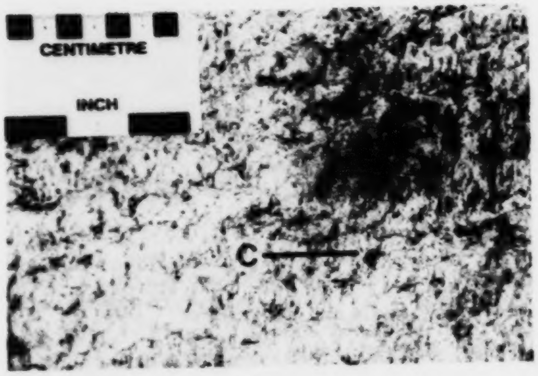


Figure 7 – C-S fabrics in the shear hosting the James-Jasper deposit in the Island Lake Pluton. The C-foliation (plane of shearing) strikes 036° and dips 84° northeast. The intersection of S-foliation with the C-foliation rakes 80° from the northeast. The photograph is taken of a steeply dipping surface, subparallel to the C-foliation. The intersection of C and S with the surface is shown in the photograph, thus demonstrating the steep plunge to the C-S intersection.

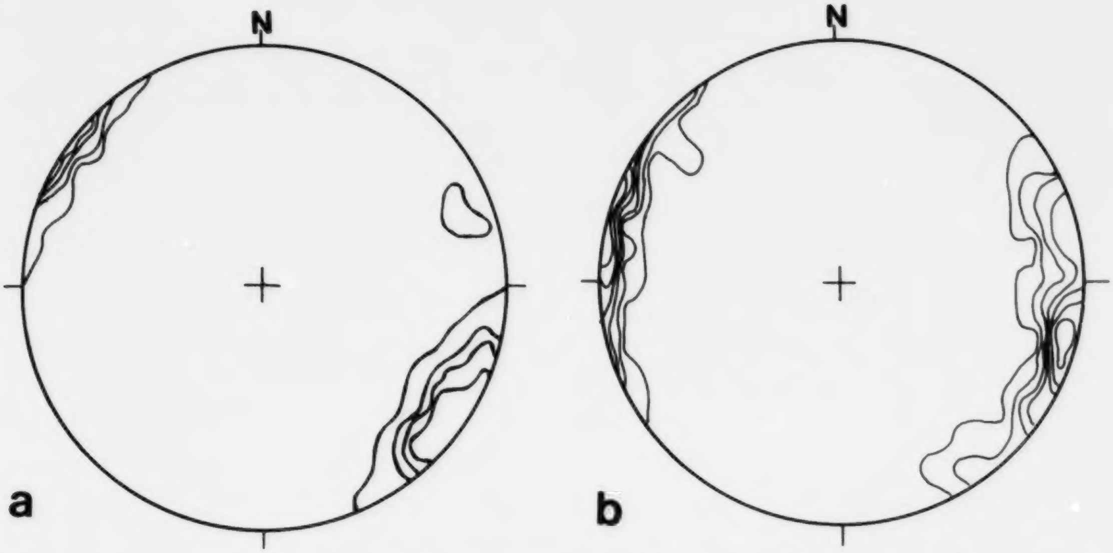


Figure 8 – Stereographic plots for the James deposit, Island Lake Pluton. a) Stereographic projection of poles to shear structures (74 points; contour interval: 4% per 1% area). b) Stereographic projection of poles to quartz veins. (47 points; contour interval: 4% per 1% area).. The poles to the shears and the veins fall on a great circle near the perimeter of the stereonet, reflecting the steep dip of the structures and the near vertical attitude of their line of intersection.

are oblique to the general trend. The C-S fabrics (Figure 7) and the closure of the minor folds shown in the map indicated a right-handed sense of shear movement. Thus the vein-bearing oblique shears have the geometry of P-shears.

The steeply plunging line of intersection of the C-S fabrics in Figure 7 is a very good indication that the sense of movement is horizontal or approximately 30°. The stereographic plot of the poles to the shear structures and the veins (Figures 8a and 8b) fall on a great circle close to the perimeter of the stereonet, which reflects the steep dip of the structures and the steep plunge of their line of intersection. This again is in agreement with strike slip movement of the shear. The linear orebodies that make up the deposit are parallel to the plunge of the line of intersection of the planar structures.

3. Discussion

The following conclusions may be made from this brief examination of the structures and deposits of the Star Lake and Island Lake Plutons.

1) Deformation outside the shear zones involves the development of the same, steeply plunging, northeast lineation that occurs within the shear zones. Furthermore, the planar fabrics indicate that the deformation outside the shear zones involves a component of rotational strain.

2) An analysis of the planar structures (foliations, shear planes and veins) in the shear zones demonstrates that the steep northeast lineation is an intersection lineation, and that shear displacement was primarily strike slip.

3) the plunge of the gold-bearing vein deposits is perpendicular to the direction of shear. This is well demonstrated in the steeply plunging orebodies at the Jasper deposit which are associated with strike slip movement. The same relationship between the geometry of the deposit and shear direction can be recognized at the Jolu mine, but here mineralization is associated with a localized shearing event which post dates the strike slip shearing, and involves a change of the shear direction from a 10° plunge southwest to a 30° plunge northeast. From the description given in Poulsen *et al.* (1986b), it appears that a similar structural setting occurs at the Star Lake mine. These observations are important from the point of view of exploring for ore within the confines of a deposit, but the significance of the later oblique slip movements in terms of exploring for new deposits in the shear zones is difficult to evaluate, since mineralization is also associated with (apparently) earlier strike slip movement.

The coincidence, or approximate coincidence, of an extension lineation with an intersection lineation, as described in this report, is a common occurrence in greenstone belts, and probably in other geological settings. In their earlier reports, Poulsen *et al.* (1986a,b) interpreted the direction of shear in the shear zones as being parallel to the northeast lineation. In their later report, (Poulsen *et al.*, 1987), apparently as a result of work beyond the Star Lake Pluton, they noted that the steeply plunging lineation was not confined to the shear zones, which prompted them to suggest "that the ubiquitous "down-dip" lineations in the Star Lake area are not necessarily diagnostic of slip directions in shear zones but are perhaps the product of a regional extension which was coeval with shear zone development." The observations recorded in this report agree with this statement. In its simplest form, the model of deformation for the Star Lake Pluton involves regional crustal shortening with near vertical extension, as indicated by the regional lineation, coincident with dextral strike slip movement on the 060° shear zones. However, rotational strain is not confined to the 060° shear zones but is represented by minor shears in the regionally deformed rocks. This may have some significance in mineral exploration since mineralization has been found in the Island Lake Pluton in shears striking 035° (Jasper), 010° (Roxy) and 070° (Ross).

4. References

Poulsen, K.H., Ames, D.E. and Galley, A.G. (1985): Structural studies of gold mineralization in the La Ronge area; *in* Summary of Investigations 1985, Sask. Geol. Surv., Misc. Rep. 85-5, p96-98.

______ (1986a): Controls on gold mineralization in the Star Lake Pluton, La Ronge Domain; *in* Summary of Investigations 1986, Sask. Geol. Surv., Misc. Rep. 86-4, p 139-140.

______ (1986b): Gold mineralization in the Star Lake Pluton, La Ronge belt, Saskatchewan: a preliminary report; *in* Current Research, Part A, Geol. Surv. Can., Pap. 86-1A, p205-212.

Poulsen, K.H., Ames, D.E., Galley, A.G., Derome, I. and Brommecker, R. (1987): Structural studies in the northern part of the La Ronge domain; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p107-114.

Roberts, R.G. and Tyedmers, P.H. (1988): Structural controls of the Box and Athona deposits, Goldfields, Saskatchewan: progress report; *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p.82-83.

Thomas, D.J. (1985): Geology of an area around Star Lake; Sask. Energy Mines, Open File Rep. 85-6, 83p.

La Ronge Gold Belt Geology: Gold Deposits in the Byers Fault Area (part of 64D-4)

by P. L. Schwann

Schwann, P.L. (1989): La Ronge gold belt geology: gold deposits in the Byers Fault area; *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

The Byers Fault is a regional, 26 km long, east to northeast-trending structure which hosts numerous gold showings. Other gold occurrences are located along subordinate, subparallel faults to the south. The majority of these gold occurrences are epigenetic, quartz + sulphide ± carbonate-healed shear and tension veins within volcanics and felsic to mafic intrusives (Coombe *et al.*, 1985). The Byers Fault was first recognized as a major "auriferous" structure from assessment work carried out in the Augustus Concession in the early sixties (SEM Assessment files 64D4-NE-001 to 005). Coombe *et al.* (1985) compared the structure with similar regional breaks in Archean gold camps (Kirkland - Larder Lakes and Malarctic Val d'Or).

The present multi-year study of gold mineralization associated with the Byers Fault and subparallel ancillary faults (Oven, Bean Lake Faults) was initiated to document the characteristics and controls (structural, lithological, alteration) of associated gold mineralization. Work was started in the Weedy Lake area at the northeast extremity of the Byers Fault and in the Oven - Corner Lakes area along the subordinate Oven Lake Fault.

Previous work in the area by the Saskatchewan Geological Survey was carried out by Byers (1948), Johnston (1969), Kirkland (1959) and Harper, (1984, 1985). Descriptions of several of the gold prospects are presented by Beck (1959), Thomas (1987) and Netolitsky (1986), while Coombe (1984) presented an overview of gold deposits in the La Ronge Domain. More recently the Geological Survey of Canada has undertaken structural studies in the area (Poulsen 1986, Poulsen *et al.* 1987).

1. Weedy Lake

An area to the northwest of Weedy Lake encompassing the Weedy Lake "Golden Heart" and "B Zone" deposits was geologically mapped at 1:1000 scale.

a) Description of Rock Types[1]

Extrusive Rocks:

Intermediate and felsic volcanic rocks occur in the southwest and northwest part of the map area. Andesitic massive, to amygdaloidal and porphyritic flows and pyroclastics including crystal ash tuffs, lapilli tuffs and agglomerate are predominant. Fresh surfaces are dark grey to green, weathered surfaces are green and white. Flows are feldspar and amphibole phyric and may contain 0.5 cm to 1.0 cm quartz amygdales. A distinctive plagioclase phyric andesite (glomerophyric) outcrops near the shore of Weedy Lake. Plagioclase laths from 1 to 10 mm long occur as clusters in an aphanitic groundmass and comprise up to 20 percent of the rock. Andesitic crystal ash tuffs are finely graded and interlayered on a 0.1 to 1.0 m scale with lapilli tuff. Agglomerate is restricted to the southwest part of the area. It is clast supported, heterolithic and contains felsic and mafic phyric and aphyric clasts including fragments of the glomerophyric andesite. Clasts range from 1 to 50 cm and are generally rectangular.

Dacite, a subordinate rock type comprising quartz (50 - 60 percent), biotite (15 - 20 percent) and feldspar (25 percent), varies from aphanitic to quartz phyric massive units interlayered with andesite. Quartz eyes are 1 to 2 mm diameter and constitute up to 15 percent of the rock. Fresh surfaces are blue grey, outcrops are jointed and weather buff to pale grey.

Intrusive Rocks:

Diorite - quartz diorite and gabbro stocks and sills intrude the volcanic sequence. Diorite, which outcrops immediately to the northwest of Weedy Lake, was the focus of the mapping project. It is compositionally variable from diorite to quartz diorite, is greyish-green, medium grained, equigranular, weakly to strongly foliated and weathers green and white. Feldspars (50 - 60 percent), amphibole and biotite (30 - 40 percent) and quartz (5 - 10 percent) are the principal mineral constituents. A leucoxene-bearing (5 - 7 percent) diorite observed in drill core was not encountered on surface.

Gabbro represents a minor rock type in the northwest extremity of the area, cropping out immediately south of a linear depression referred to as Byers swamp. It is a coarse-grained, weakly foliated, green and bluish-white rock which weathers green and white. It is composed of plagioclase (70 - 80 percent) with pyroxene and amphibole (20 - 30 percent).

Dykes:

Mafic and felsic dykes cut the diorite, gabbro and volcanic rocks. The mafic dykes are well foliated, dark grey

---

(1) The following descriptions are based on field observations without the benefit of thin section or chemical analysis.

and weather brownish-grey. They contain 1 to 10 mm biotite porphyroblasts aligned with their long axis in the foliation. Felsic dykes are variably microgranitic, feldspar phyric and aphyric. They are weakly to moderately foliated, light grey to blue, with pink grey to buff weathered surfaces. Biotite and feldspar are aligned with their long axes in the foliation.

b) Structure

The regional structure and metamorphic geology has been summarized by Harper (1984, 1985). At Weedy Lake the diorite and volcanics exhibit both S and L fabrics. Foliations strike from 030° to 060° and dip steeply to the northwest. Lineations, defined by both mineral orientation and clast elongation trend northwest and plunge subvertically. In the gabbro a mafic mineral alignment plunges shallowly to the north.

Macrostructures are manifest as a series of subparallel, northeast-striking, steeply northwest-dipping shear zones which are topographically expressed as a series of ridges. The two most prominent shears are informally referred to as the Weedy Lake Shear which parallels the northwest shore, and the B Zone Shear approximately 75 m to the west. These zones are subparallel to the regional Byers Fault which is thought to pass through the swamp to the northwest of the diorite/volcanic contact (Harper, 1985). S - C fabrics and tension gash orientation indicate a dextral movement component on the shear zones.

The Weedy Lake Shear zone strikes from 040° to 050° and typically dips steeply to the northwest, although at two locations a steeply southeast dip was measured. In the diorite the shear zone is recorded by narrow (metre wide) phyllonite unit bordered by strongly foliated diorite. Volcanics in the shear zone are flaggy and schistose.

The B Zone Shear proper is poorly exposed on surface, strikes from 040° to 050° and dips steeply to the northwest. Diorite in the B Zone shear is strongly foliated, but not phyllonitic; rotated and sheared diorite clasts are enclosed in an anastomosing complex of chloritic shear planes whereas the volcanics are strongly foliated and schistose.

Mineral lineations, defined by the preferred orientation of the long axes of amphibole and biotite, plunge subvertically to the northwest and similarily oriented elongate lapilli indicate this direction as an extension axis.

c) Deposit Geology

Gold mineralization on the Weedy Lake property is structurally controlled, occuring in: (1) sheared, silicified and pyritized diorite (low grade "B Zone" and higher grade "Golden Heart" deposit), and/or (2) sheared quartz veins in the diorite and volcanic rocks (HW #1 and HW #2 Veins), as well as at the contact of the diorite and volcanics (Contact Vein).

The Golden Heart deposit is a tabular, moderately northeast-plunging (47°) zone of "higher grade" mineralization in the hanging wall of the B Zone Shear. It is surrounded by "lower grade" mineralization referred to as the B Zone. The Golden Heart deposit has been traced over a strike length of 288 m and down plunge for 450 m and has a true thickness which ranges from 3 to 19 m (Golden Rule Resources Progress Report, July 31, 1989). At depth the Golden Heart bifurcates into two distinct gold-bearing zones; one within the hanging wall of the B Zone Shear, the other within the footwall (Tyler Resources Inc. Progress Rept, Dec. 5, 1988).

Gold-bearing quartz veins (HW #1, HW #2 and Contact Vein) are subparallel to the B Zone Shear. The Contact Vein system occurs within a shear zone at the contact between diorite and volcanics and is continuous along strike for 200 m. It varies from a singular quartz vein up to 50 cm thick to a series of subparallel 3 to 10 cm thick veins. The HW #1 and HW #2 veins were not seen in outcrop or in core, but are described by Tyler Resources as narrow quartz veins commonly containing coarse visible gold.

Drill indicated reserves for the Golden Heart deposit, HW and Contact Veins are 745,540 tonnes grading 7g/tonne (0.255 oz/ton) Au; the lower grade B Zone deposit has reserves of 400,000 tons grading 4.5g/tonne (0.14 oz/ton) (Golden Rule Resources Progress Report, July 31, 1989).

d) Alteration

Within the mineralized zone, diorite and volcanics are strongly foliated, silicified and contain up to 10 percent disseminated pyrite and minor carbonate. The diorite also contains up to 15 percent biotite and may be veined by potassium feldspar. Sheared, pyrite-bearing quartz veins are commonly bordered by actinolite.

e) Summary

In summary, gold mineralization on the Weedy Lake property is structurally controlled within:

(1) sheared, silicified, pyritized and biotite-bearing diorite and andesite in the hanging wall of the B Zone Shear, and
(2) sheared quartz veins which are subparallel to the B Zone Shear.

Favourable exploration targets would exhibit the following characteristics:

(1) Development of strongly foliated to mylonitic fabric within an intrusive.
(2) Pyritization of the foliated host rock. As Mellinger (1986) observed, significant gold precipitation only occurs when a threshold value of pyrite precipitation is attained.
(3) Development of quartz veining and silicification within and subparallel to the shear zone.
(4) Development of alteration minerals such as biotite, carbonate and feldspar. The association of biotite with pyrite in the altered diorite suggests that potassium metasomatism may also have played a role in precipitation of gold.

Similar structurally controlled gold mineralization may be associated with the subparallel Weedy Lake Shear which also contains pyrite and shear-related quartz veins.

2. Oven Lake - Corner Lake

A project was initiated along the Oven Lake Fault to compare the styles of deformation and mineralization of the subsidiary fault structures with those of the Byers Fault. This project is still in its preliminary stages and consequently will only be briefly described.

Selected locations along the Oven Lake - Corner Lake Fault and Byers Fault were mapped. The area in general, principally consists of intermediate and felsic volcanics which are intruded by the Oven Lake and Corner Lake granite - granodiorite stocks. These intrusions are round, relatively small (2 x 3 km) stocks which respectively underlie Oven and Corner Lakes. The Oven Lake Stock is only exposed at one locality along the western shore of Oven Lake. Granitic dykes at the north end of the lake are likely related to the stock. The Corner Lake Stock is exposed along both the southwest and southeast shore of Corner Lake.

At Corner Lake area, the Oven Lake - Corner Lake Fault is expressed within the granodiorite as discrete 2 to 3 cm wide, northeasterly-striking and steep northwesterly-dipping shears within a broader high strain zone up to 15 m wide. Granite bordering the individual, narrow shears is only moderately foliated. C-S fabrics indicate a dextral movement component along the fault. Overburden precluded tracing the fault along strike into the volcanics, however, where it outcrops along the northern contact of the Corner Lake Stock with intermediate volcanics, andesites are strongly sheared and amphibole is replaced by biotite. Schistosity dips steeply to the southeast, whereas further north in the volcanics it dips subvertically to steeply to the northwest.

Both the Oven Lake and Corner Lake gold showings occur in protomylonitic to mylonitic, silicified and pyritized granodiorite within the footwall of the Oven Lake Fault.

The Byers Fault is located along the north shore of Beaver Lake approximately 350 m to the north of Oven Lake. It defines the contact of felsic volcanics to the south and the Boundary Lake Pluton, and is marked by a 150 m wide, east-northeasterly-trending linear depression. Felsic volcanics adjacent to the inferred fault are protomylonitic, strike northeast and dip steeply to the southeast. The footwall granodiorite of the Boundary Lake Pluton is relatively weakly foliated. Volcanic rocks between the Byers and Oven Lake Faults consistently exhibit well developed L-S fabrics.

3. Acknowledgements

Pamela Cook ably assisted in field and office work. Her company was an enjoyable addition. The members of the exploration crews of Golden Rule Resources - Camp Waddyacallit (Weedy Lake Property) and Cameco (Oven - Corner Lakes Property) are thanked for their gracious hospitality, logistical support and helpful consultations regarding the geology of the deposits. This study has benefited from discussions with Dr. R.G. Roberts, Dr. T.I.I. Sibbald and D.J. Thomas.

4. References

Beck, L.S. (1959): Mineral occurrences in the Precambrian of northern Saskatchewan (excluding radioactive minerals); Sask. Dep. Miner. Resour., Rep. 36, 135p.

Coombe, W. (1984): Gold in Saskatchewan; Sask. Energy and Mines, OF Rep. 84-1, 134p.

Coombe, W., Lewry, J.F., and Macdonald, R. (1985): Regional geological setting of Gold in the La Ronge Domain, Saskatchewan; *in* Gold in the Western Shield, Clark L.A. (ed.), C.I.M. Spec. Vol. 39, p25-56.

Golden Rule Resources Ltd. Progress Report, July 31, I989.

Harper, C.T. (1984): Geological mapping, Waddy Lake area (part of NTS 64D-4 and -5); *in* Summary of Investigations 1984, Sask. Geol. Survey, Misc. Rep. 84-4, p6-20.

__________ (1985): Bedrock geological mapping, Waddy - Tower Lakes Area (part of NTS 64D-4 and -5 and 74A-1 and -8); *in* Summary of Investigations 1985, Sask. Geol. Survey, Misc. Rep. 85-4, p6-17.

Johnston, W.G.Q. (1969): The geology of the eastern portion of the Waddy Lake area, Saskatchewan; Sask. Dep. Miner. Resour., Rep. 127, 43p.

Kirkland, S.J.T. (1959): The geology of the Brabant Lake area, Saskatchewan; Sask. Dep. Miner. Resour., Rep. 33, 31p.

Mellinger, M. (1986): Lithogeochemistry related to gold mineralization in Saskatchewan; *in* Gold in the Western Shield, Clark L.A. (ed.), C.I.M. Spec. Vol. 38, p253-271.

Netolitzky, R.K. (1986): An exploration review of the Weedy Lake, Tower Lake and Wedge Lake gold deposits, Saskatchewan; *in* Gold in the Western Shield, Clark L.A. (ed.), C.I.M Spec. Vol. 38, p229-252.

Poulsen, K. H. (1986): Auriferous shear zones with examples from the Western Shield; *in* Gold in the Western Shield, Clark L.A. (ed.), C.I.M. Spec. Vol. 38, p86-103.

Poulsen, K.H., Ames, D.E., Galley, A.G., Derome, I., and Brommecker, R. (1987): Structural studies in the northern part of the La Ronge Domain; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p107-115.

Thomas, D.J. (1987): Gold deposits of the La Ronge Domain; GAC/MAC Field Trip No. 4 Guidebook, GAC/MAC Joint Annual Meeting, I987, Saskatoon, Sask.

Tyler Resources Inc. Progress Report, Dec. 5, 1988.

Geology of the Douglas Lake - Phantom Lake Area
(Part of NTS 63K-12 and -13)

David J. Thomas

Thomas, D.J. (1989): Geology of the Douglas Lake - Phantom Lake area (Part of NTS 63K-12, -13); *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

A revisional geological mapping program was initiated in the Amisk Lake - Flin Flon region in 1989. The purpose of this project is to improve the understanding of relationships among the Amisk Group stratigraphy, tectonic events and metallogenesis in this region. Field work in 1989 involved 1:12,500 scale mapping of about 26 km^2 between Phantom Lake, Bootleg Lake and the townsite of Creighton.

Previous reconnaissance and detailed geological surveys undertaken by the Geological Survey of Canada throughout the greater Flin Flon - Amisk Lake region include: Tyrrel (1902), McInnes (1909), Bruce (1918), Alcock (1923), Ambrose (1936a,b), Tanton (1941a,b), Stockwell (1960) and Heywood (1966). More recent federal and provincial geological survey investigations incorporating the Douglas Lake - Phantom Lakes area include Byers *et al*. (1965), Pearson (1979, 1981, 1983, 1984), and Galley and Franklin (1987).

1. Regional Geology

The Douglas Lake - Phantom Lake area is situated within the Aphebian volcanoplutonic Flin Flon - Snow Lake Belt. This belt is transitional northwards into higher grade rocks of the Kisseynew Gneiss Belt (Ashton *et al*., 1987) and is unconformably overlain to the south by flat-lying Ordovician dolomites (Figure 1). The Amisk Group, which forms the oldest group of rocks in the region, comprises a metamorphosed assemblage of predominantly subaqueous mafic flows and flow breccias, subordinate felsic flows and porphyries, lesser volcaniclastic and sedimentary rocks, and a suite of syn- to post-volcanic dykes and sills. The group is unconformably overlain by metamorphosed alluvial sandstones and conglomerates of the Missi Group. Post-Missi intrusions include a suite of ultramafic to felsic rocks, the Boundary intrusions (Stockwell, 1946, 1960; Syme and Forester, 1977), and the Boot Lake - Phantom Lake Complex (Galley and Franklin, 1987), a younger composite intrusion ranging from gabbro to granite.

Bailes and Syme (1987) recognize one phase of pre-Missi folding (P1) and four phases of post-Missi folding (P2 to P5) in the Flin Flon area. Strong north-, northeast- and northwest-trending fault systems dominate the Flin Flon region. A number of these faults have been identified as major boundaries which separate allocthonous blocks of distinctively different stratigraphic and metamorphic character (Bailes and Syme, 1987; Syme, 1986, 1987, 1988).

U-Pb zircon ages obtained from the Manitoba portion of the Flin Flon belt indicate an age of Amisk volcanism

LEGEND

POST - MISSI INTRUSIONS

Bootleg Lake - Phantom Lake Intrusion

- ⊞ Microcline porphyritic granite (Phase 4)
- ⁘ Gabbro, diorite, granodiorite (Phases 1 to 3)

Boundary Intrusions

- ⁘ Pyroxenite, gabbro, meladiorite, leucodiorite, granodiorite

AMISK GROUP VOLCANICS

Douglas Lake Assemblage

- ○ Mafic to intermediate volcaniclastic rocks; minor mafic flows

Beaver Road Assemblage

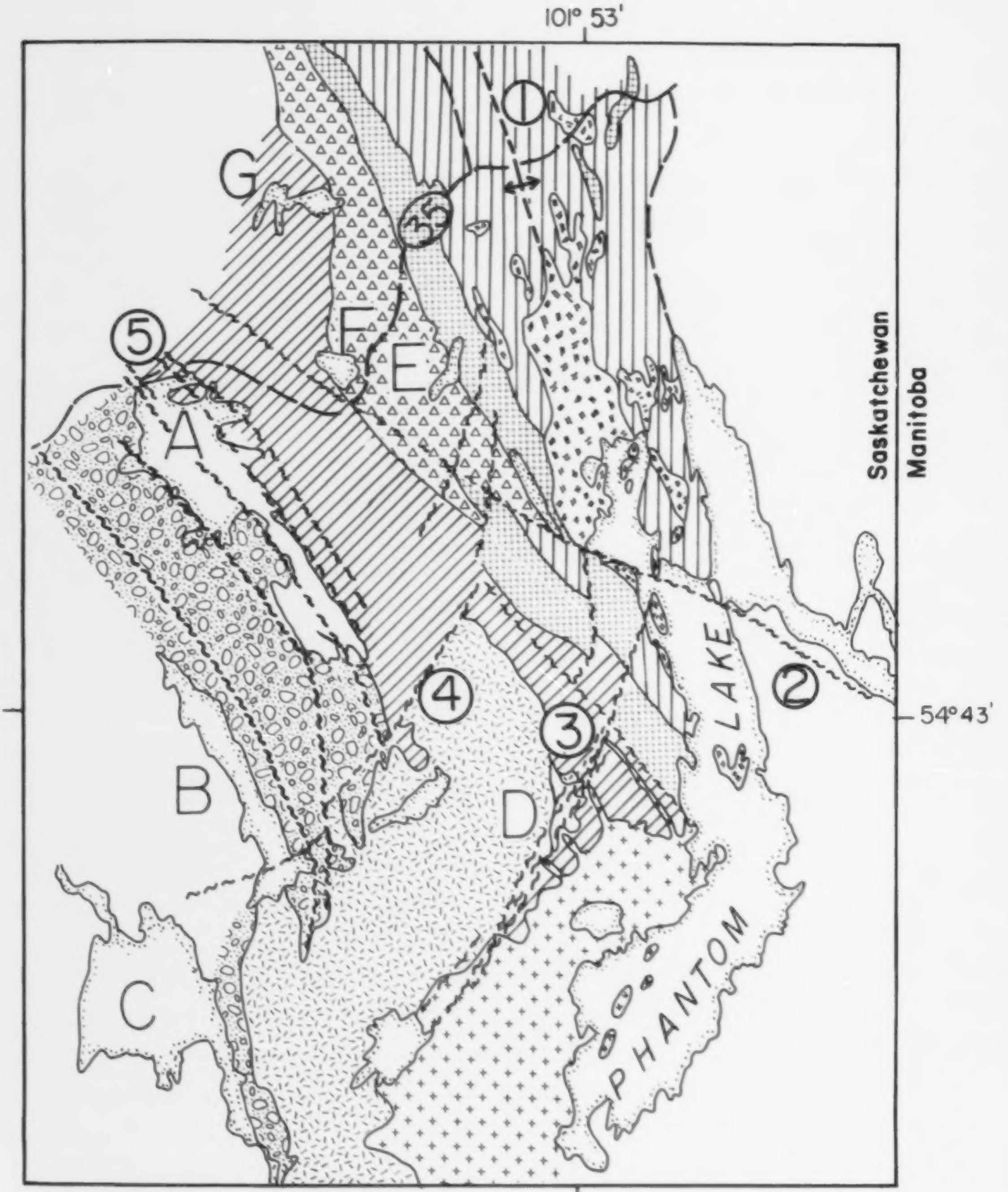
- ▨ Newcor member: mafic pillow flows and flow breccias
- △ Bomber Lake member: aphyric mafic flows, minor pillow flows and mafic tuffs
- ▦ Myo Lake member: felsic flows and porphyries, minor felsic fragmentals
- ▥ Creighton member: mafic pillow flows, flow breccias, minor tuffs

∿∿ ∿∿ Fault, shear

—‡— Anticlinal trace

35 Highway

Figure 1 – (Opposite) Geological sketch map of the Douglas Lake - Phantom Lake area. A, Douglas Lake; B, Bootleg Lake; C, Wekach Lake; D, Dion Lake; E, Mayo Lake; F, Bomber Lake; G, Key Lake. (1) Beaver Roak Anticline; (2) Phantom Lake Fault; (3) Dion Lake Structural Zone; (4) Rio Fault; (5) Douglas Lake Structural Zone.


101° 53'
①
G
35
⑤
F
E
A
Saskatchewan
Manitoba
LAKE
②
④
③
54° 43'
B
D
C
PHANTOM
0
1
2
3
4 KM

around 1886 Ma (Syme *et al*., 1987), and deposition of Missi Group rocks around 1832 Ma (Gordon *et al*., 1987). A U-Pb zircon age of 1820 Ma is reported from a granite dyke cutting the Missi Group (MacQuarrie, 1980). The regional geology of the of the Flin Flon area has been reviewed by Stauffer and Mukherjee (1971), Stauffer *et al*. (1975), Price (1977), Syme (1986, 1987, 1988) and Bailes and Syme (1987).

2. Amisk Group Volcanics

Amisk Group rocks in the Douglas Lake - Phantom Lake area are folded into the north-trending Beaver Road anticline (Stockwell, 1960). The majority of the area mapped in 1989 occupies the western limb of this structure and is a homoclinal westerly-younging sequence (Figure 1). A preliminary stratigraphic subdivision of Amisk Group rocks in the Douglas Lake - Phantom Lake area is proposed by the author (Figure 2):

1) The Beaver Road Assemblage is composed of mafic flows and flow breccias, subordinate rhyolitic to dacitic flows, fragmentals, intrusive porphyry, and minor mafic to felsic tuffs. A high volume of synvolcanic basic to intermediate dykes and sills intrude this assemblage.
2) The Douglas Lake Assemblage is composed predominantly of intermediate to mafic pyroclastic and volcaniclastic deposits with minor intercalated subaqueous mafic flows. There are fewer synvolcanic sills and dykes than in the Beaver Road Assemblage.

a) Beaver Road Assemblage

The Beaver Road assemblage forms the lowest stratigraphic portion of the Amisk Group succession in the Douglas Lake - Phantom Lake area. A rough estimation across the western limb of the Beaver Road anticline indicates a minimum thickness of 2500 m for this assemblage. The assemblage underlies the area east of Douglas Lake and can be further subdivided into four main members (Figure 1); Creighton member, Myo Lake member, Bomber Lake member, and Newcor member.

Creighton Member:

The Creighton member, which has a minimum thickness of 550 m and forms the basal part of the Beaver Road assemblage, is composed of a mixed sequence of mafic pillow flows, subordinate massive mafic flows, and minor mafic to intermediate crystal, lapilli and ash tuffs.

Plagioclase-phyric mafic flows comprise about 50 percent of the member. They typically weather greyish orange to pale olive and are pale green to medium bluish grey on fresh surface. Plagioclase phenocrysts range from 0.25 to 0.75 cm long and comprise 10 to 30 percent of the rock. Glomeroporphyritic plagioclase-rich flow horizons are locally present in the sequence. Quartz amygdules, generally less than 1.0 mm diameter, form up to 10 percent of the rock. The plagioclase-phyric flows are predominantly pillowed although massive varieties commonly form the basal portion of pillow flow units, and locally form individual flows up to several tens of metres thick. Plagioclase-phyric pillow buds are typically turnip-shaped in cross section and are rarely greater than 1.5 m diameter, although basal pillows locally exceed 2 m diameter.

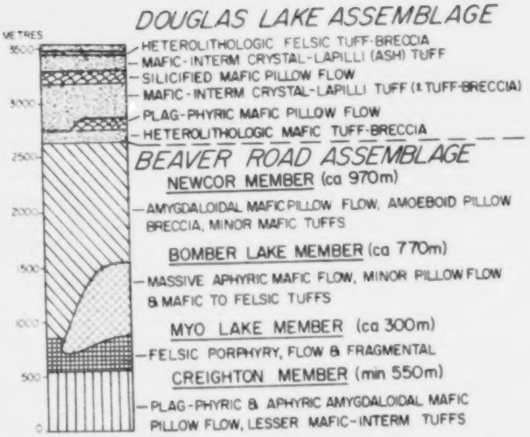

DOUGLAS LAKE ASSEMBLAGE
METRES
3500
3000
2500
2000
1500
1000
500
0
HETEROLITHOLOGIC FELSIC TUFF-BRECCIA
MAFIC-INTERM CRYSTAL-LAPILLI (ASH) TUFF
SILICIFIED MAFIC PILLOW FLOW
MAFIC-INTERM CRYSTAL-LAPILLI TUFF (± TUFF-BRECCIA)
PLAG-PHYRIC MAFIC PILLOW FLOW
HETEROLITHOLOGIC MAFIC TUFF-BRECCIA
BEAVER ROAD ASSEMBLAGE
NEWCOR MEMBER (ca 970m)
AMYGDALOIDAL MAFIC PILLOW FLOW, AMOEBOID PILLOW BRECCIA, MINOR MAFIC TUFFS
BOMBER LAKE MEMBER (ca 770m)
MASSIVE APHYRIC MAFIC FLOW, MINOR PILLOW FLOW & MAFIC TO FELSIC TUFFS
MYO LAKE MEMBER (ca 300m)
FELSIC PORPHYRY, FLOW & FRAGMENTAL
CREIGHTON MEMBER (min 550m)
PLAG-PHYRIC & APHYRIC AMYGDALOIDAL MAFIC PILLOW FLOW, LESSER MAFIC-INTERM TUFFS

Figure 2 - Preliminary stratigraphic subdivision of the Amisk Group in the Douglas Lake - Phantom Lake area.

Quartz (feldspar) amygdalodial-rich mafic flows comprise about 40 percent of the Creighton member. These rocks are dark green to greenish grey on fresh surfaces and typically weather to pale olive to pale yellowish brown. Quartz (feldspar) amygdules comprise 10 to 20 percent of the rock and are generally 0.5 to 15.0 mm diameter, although some exceed several centimetres. The quartz (feldspar) amygdalodial pillows are highly variable in shape, ranging from bulbous to elongate in cross-section, and from less than 0.5 m to greater than 2.0 m diameter. Pillow buds at the top of flow units commonly grade upwards into amoeboid pillows and amoeboid breccias. Elsewhere, pillows are directly overlain by hyaloclastic and pillow breccia detritus. Interpillow hyaloclastic material, radial pipe amygdules and concentric contraction cracks are more commonly developed in the quartz feldspar amygdalodial flows than in plagioclase-phyric pillow flows.

Heterolithologic mafic to intermediate plagioclase crystal - lithic tuffs, and minor laminated ash tuffs comprise about 10 percent of the Creighton member. Finely-laminated felsic ash tuffs form a minor component. The rocks weather a light olive grey, yellowish grey to greyish orange and are pale green to medium dark grey on fresh surfaces. Tuffaceous beds commonly occur near the contact between plagioclase-phyric flows and quartz (feldspar) amygdalodial flows (Figure 3). Individual tuff deposits vary from one metre to several tens of metres thick and rarely exceed 1000 m strike length. The tuffs vary from thinly laminated (1 to 3 mm) to thickly bedded (30 to 100 cm), and commonly display well-developed cross-laminated bedding, and normal, reverse and density grading. The tuffs appear to be largely subaqueous, but, local subaerial conditions are indicated by accretionary lapilli, symmetrically graded bedding and unsorted pumaceous fragments in normally-graded crystal tuff beds.

A number of small rhyolitic to dacitic mixed porphyry/fragmental bodies were mapped on the eastern limb of the Beaver Road anticline. Their stratigraphic position with respect to the Creighton member is uncertain and will require further mapping to the east. These bodies occur as dykes, sills and dome-like bodies. The dome-like bodies (ca. 60 m thick) consist of massive quartz-phyric and aphyric cores overlain and flanked by aprons of felsic fragmentals. Immediately west and southwest of the HBMS's South Main shaft, a series of small rhyolitic bodies with felsic fragmentals are located at the contact between a lower series of quartz amygdalodial mafic pillow flows and an overlying package of plagioclase-phyric pillow flows. Several of these felsic bodies appear as small domes extruded during a hiatus in subaqueous mafic volcanism, and might therefore also define a stratigraphic horizon favourable for volcanogenic - exhalitive mineralization.

Myo Lake Member:

The Myo Lake member is about 300 m wide and can be traced for at least 6400 m along strike. It overlies the Creighton member on the western limb of the Beaver Road anticline and is composed of rhyolitic to dacitic flows, flow breccias, intrusive porphyries and various felsic fragmentals. Laminated felsic ash tuff and aphyric mafic flows form minor components of this member.

Quartz (feldspar) rhyolite to rhyodacite porphyry composes about 40 percent of the Myo Lake member. The rocks are typically very fine grained and flinty with weathered surfaces olive grey to greyish yellow and uniformally medium grey to bluish grey fresh surfaces. Quartz phenocrysts range from 1.0 to 3.0 mm diameter and comprise 5 to 20 percent of the rock. Feldspar phenocrysts are more prevalent in rhyodacitic varieties and account for 5 to 10 percent of the rock. Intrusive contacts between the porphyries and the country rocks range from highly irregular and brecciated to very linear and sharp.

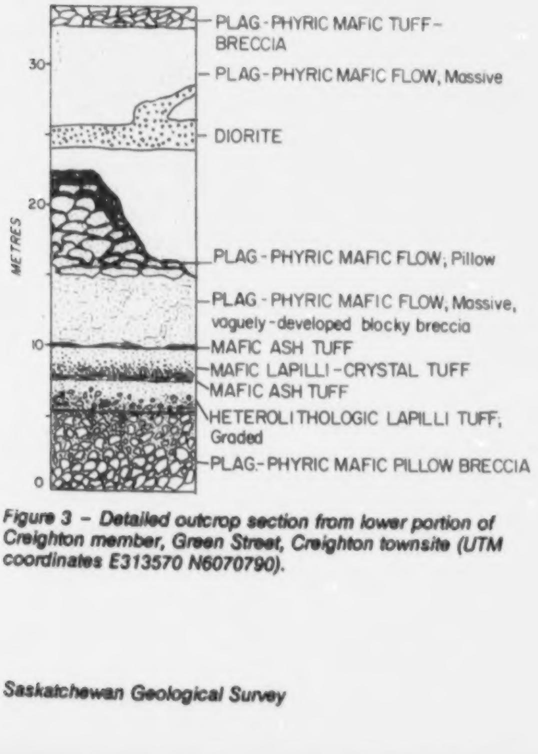

PLAG-PHYRIC MAFIC TUFF-BRECCIA
PLAG-PHYRIC MAFIC FLOW, Massive
DIORITE
PLAG-PHYRIC MAFIC FLOW; Pillow
PLAG-PHYRIC MAFIC FLOW; Massive, voguely-developed blocky breccia
MAFIC ASH TUFF
MAFIC LAPILLI-CRYSTAL TUFF
MAFIC ASH TUFF
HETEROLITHOLOGIC LAPILLI TUFF; Graded
PLAG.-PHYRIC MAFIC PILLOW BRECCIA
30
20
10
0
METRES

Figure 3 – Detailed outcrop section from lower portion of Creighton member, Green Street, Creighton townsite (UTM coordinates E313570 N6070790).

Feldspar (quartz) dacite porphyrys and breccias comprise about 50 percent of the Myo Lake member (Figure 4). They are typically very fine-grained flinty rocks and have a higher specific gravity than their rhyolitic counterparts. The rock is dark grey to greenish black on fresh surfaces and weathers dark yellowish brown to greyish orange. Textures varies from aphyric to plagioclase porphyritic with phenocrysts 1.0 to 2.0 mm diameter comprising 5 to 20 percent of the rock. Quartz phenocrysts (1.0 to 2.0 mm) are less common and make-up more than 5 percent of the rock. Disseminated pyrite and chalcopyrite occur locally. The rock is commonly laced by an anastomosing network of chloritic and epidote veinlets, and generally is quite friable and rubbly due to closely spaced extension and shear fractures.

Felsic fragmentals ranging from fine-grained crystal - ash tuffs to coarse tuff-breccias form about 10 percent of the Myo Lake member. The rocks vary from monolithologic with clast-supported frameworks to heterolithologic with mafic matrix-supported framework. The lapilli and tuff-breccia units range from massive to crudely layered. Felsic clasts are predominantly angular to subangular and range from several centimetres to a metre in length. The coarser fragmentals commonly overlie or are gradational along strike with, more massive rhyolitic to dacitic rocks (Figure 5). These rocks may represent a range of deposits made-up of autobrecciated flow material, co-eruptive fall material, as well as mechanically degraded material (e.g. talus deposits, lahars, debris flows).

Bomber Lake Member:

The Bomber Lake member is characterized by massive **aphyric mafic flows**, subordinate **pillow flows**, and minor **mafic lapilli and ash tuff** (Figure 6). This member is in part intercalated and transitional with the underlying Myo Lake member and forms a northwesterly-thickening horizon between Bomber, Myo and Key Lakes. Similar aphyric mafic flows occur on the east limb of the Beaver Road anticline where they are intercalated with mafic pillow flows of the Creighton member and minor felsic volcanics. The flows typically weather pale yellowish brown to light brown and are dark greenish grey to greenish black on fresh surface. The rocks are fine to medium grained, generally nonporphyritic and massive, although locally contain 5 percent quartz amygdules and sparse plagioclase phenocrysts. The aphyric flows, generally less than a few metres thick, form composite or compound flow units which texturally and compositionally resemble the diabase dykes and sills that intrude them.

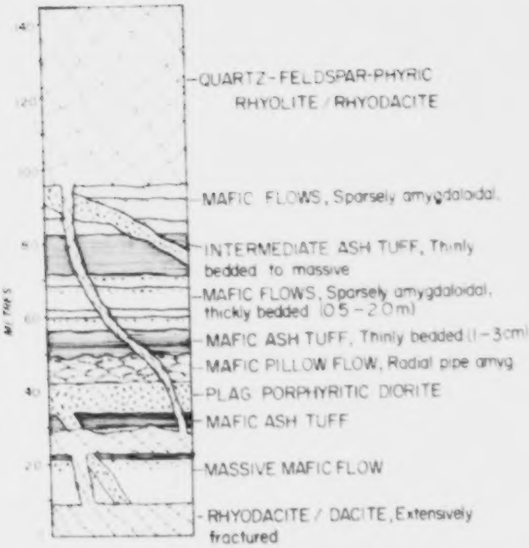

140
120
100
80
60
40
20
0
METRES
QUARTZ-FELDSPAR-PHYRIC RHYOLITE / RHYODACITE
MAFIC FLOWS, Sparsely amygdaloidal.
INTERMEDIATE ASH TUFF, Thinly bedded to massive
MAFIC FLOWS, Sparsely amygdaloidal, thickly bedded (0.5 – 2.0 m)
MAFIC ASH TUFF, Thinly bedded (1 – 3cm)
MAFIC PILLOW FLOW, Radial pipe amyg
PLAG PORPHYRITIC DIORITE
MAFIC ASH TUFF
MASSIVE MAFIC FLOW
RHYODACITE / DACITE, Extensively fractured

Figure 4 – Detailed outcrop section from Myo Lake member, West Arm Mine road (UTM coordinates E313670 N6068465).

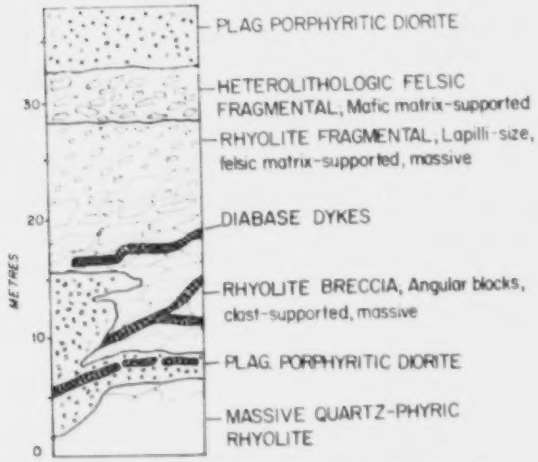

30
20
10
0
METRES
PLAG PORPHYRITIC DIORITE
HETEROLITHOLOGIC FELSIC FRAGMENTAL, Mafic matrix-supported
RHYOLITE FRAGMENTAL, Lapilli-size, felsic matrix-supported, massive
DIABASE DYKES
RHYOLITE BRECCIA, Angular blocks, clast-supported, massive
PLAG. PORPHYRITIC DIORITE
MASSIVE QUARTZ-PHYRIC RHYOLITE

Figure 5 – Detailed outcrop section from the Myo Lake member, West Arm Mine road (UTM coordinates E313335 N6067700).

Newcor Member:

The Newcor member is comprised of a thick sequence of quartz - feldspar **amygdalodial mafic pillow flows** and **amoeboid mafic pillow breccias** which are intercalated with and overlie the Bomber Lake member in the northwest and the Myo Lake member in the southeast. The flows of the Newcor member are extremely rich in amygdules and contain between 10 to 30 percent quartz and feldspar amygdules ranging from 0.1 to 5.0 cm diameter. The rocks are compositionally and texturally very similar to the quartz (feldspar) amygdalodial flows of the Creighton member but differ from them in a higher proportion of amoeboid mafic pillows and pillow breccias. Immediately east of Douglas Lake the ameoboid pillow flows and flow breccia deposits are several tens of metres thick and account for more than 40 percent of the succession. The high volume of ameoboid pillows and ameoboid breccias may be the products of subaqueous lava fountaining in a near vent environment. Similar rocks have been described by Syme (1987) in the Manitoba portion of the Flin Flon belt . The uppermost 180 m of the Newcor member consist of sparsely amygdaloidal magnetite-bearing mafic pillows. The pillows are generally less than 1.0 m diameter and have a distinctive lozenge to lensoid cross-section in contrast to the more oval and bulbous pillow sections observed in the underlying quartz + feldspar amygdalodial pillow flows. The rocks are greenish black on fresh surface, weather pale green to greyish green, and contain up to 5 percent euhedral magnetite crystals disseminated throughout the pillows.

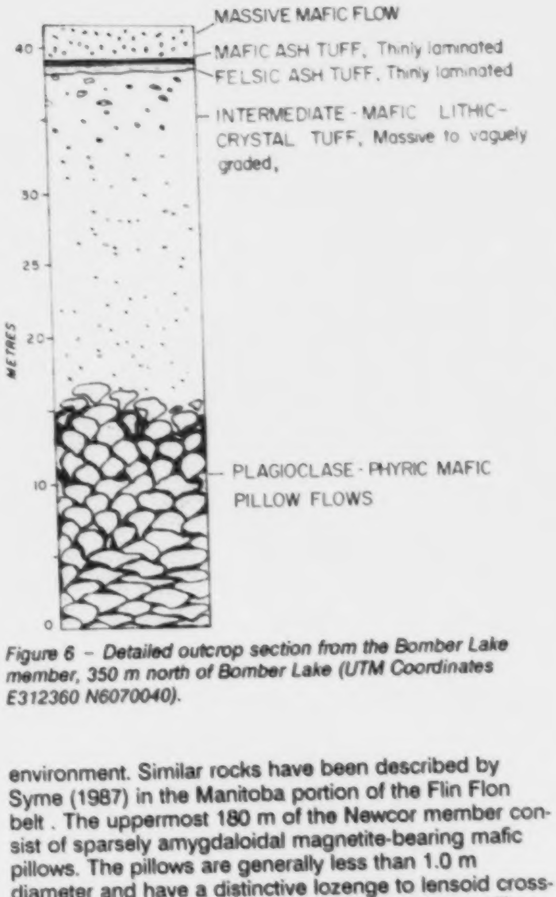

40
30
25
20
10
0
METRES
MASSIVE MAFIC FLOW
MAFIC ASH TUFF, Thinly laminated
FELSIC ASH TUFF, Thinly laminated
INTERMEDIATE - MAFIC LITHIC-CRYSTAL TUFF, Massive to vaguely graded,
PLAGIOCLASE - PHYRIC MAFIC PILLOW FLOWS

Figure 6 – Detailed outcrop section from the Bomber Lake member, 350 m north of Bomber Lake (UTM Coordinates E312360 N6070040).

b) Douglas Lake Assemblage

The Douglas Lake assemblage forms a northwest-trending sequence of predominantly volcaniclastic rocks between Douglas and Bootleg Lakes and probably extends southwest to Wekach Lake where it is intruded by the Reynard Lake pluton (Byers *et al.*, 1965; Pearson, 1979). To the southeast, the volcaniclastics are cut by the Boot Lake - Phantom Lake intrusion. The assemblage stratigraphically overlies the Newcor member of the Beaver Road assemblage. The contact is largely obscured by Douglas Lake and, where observed, is highly tectonized and altered. The assemblage appears to be monoclinal with stratigraphic tops younging to the southwest.

The lowermost portion of the Douglas Lake assemblage contains poorly-sorted **intermediate to mafic heterolithologic tuff-breccias** with subordinate intercalated **lapilli tuffs**. The rocks have a matrix-supported framework although clast-supported breccias are not uncommon. Clast compositions are highly variable although amygdalodial-rich mafic clasts similar to rocks of the Newcor member are prevalent. This basal part of the assemblage is interpreted to be largely debris flow deposits derived in part from the Beaver Road Assemblage.

Overlying and in part intercalated with the basal tuff-breccias is a mixed package, 150 to 400 m thick, of **intermediate plagioclase-rich crystal tuff, scoria lapilli tuffs**, and **heterolithologic intermediate tuff breccia** with minor **plagioclase-phyric mafic pillow flows**. The tuffaceous rocks typically weather yellowish grey, yellowish orange to yellowish brown and fresh surfaces are medium bluish grey to greenish grey. The tuffs are very thick (1.0 m) to thinly bedded (0.03 to 1.0 m) and vary from poorly-sorted (eg. scoria-rich lapilli tuffs) to very well-sorted and massive (eg. plagioclase-rich crystal tuff). Primary depositional textures and structures are preserved locally and include normal, reverse and density grading, cross laminations and scours. Locally, the high degree of sorting and rounding of fragments indicates that epiclastic processes contributed in part to the deposition of this mixed volcaniclastic package. A minor **plagioclase-phyric mafic pillow flow unit**, 100 m thick crops out along the west shore of Douglas Lake and extends for about 1000 m to the south. The rocks are extensively epidotized, locally carbonatized, pale blue green on fresh surfaces and weather greyish yellow. Pillows, generally less than 1.5 m diameter, vary from elongate to turnip-shaped in the lower portion of the flows, and are more ameoboid-shaped towards the top. Plagioclase phenocrysts range from 1 to 3 mm long and comprise 10 to 20 percent of the rock.

Overlying the mixed tuffaceous rocks are about 100 m of extensively silicified **quartz-feldspar amygdalodial mafic pillow flows** with a minimum strike length of 3 800 m. The pillows are highly attenuated, displaying length to width aspect ratios of 10:1 or greater. Although quite siliceous, with SiO_2 contents of 68 to 72 percent (Figure 7), the well-developed pillows and highly amygdaloidal textures of the flows suggest they were probably originally quite mafic.

The silicified pillow flows are overlain by a second unit of mixed tuffs composed of intermediate "pyroxene"-plagioclase crystal (± lapilli) tuff, mafic ash tuff and heterolithologic felsic breccias. The **"pyroxene" - plagioclase crystal tuffs** weather pale olive to dusky yellow and are greyish'green on fresh surfaces. The rocks are generally massive to poorly bedded and contain abundant plagioclase and retrogressed pyroxene grains ranging from 1.0 to 2.0 mm diameter. Pyroxene is largely retrogressed to actinolite and chlorite. Lapilli-size mafic to intermediate fragments comprise less than 5 percent of the crystal tuffs.

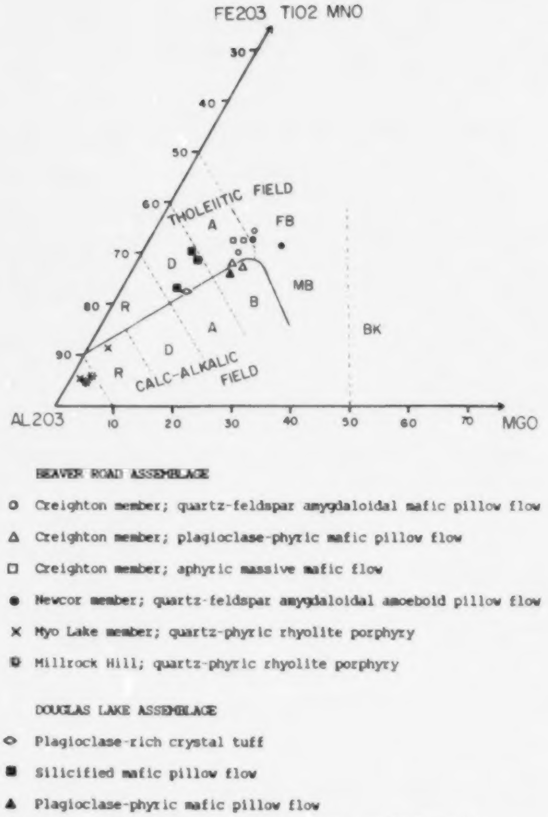


Figure 7 – Jenson cation plot of volcanic rocks from the Douglas-Phantom Lake area. R, rhyolite; D, dacite; A, andesite; B, basalt; FB, high-iron basalt; MB, high-magnesium basalt; BK, basaltic Komatiite.

The **mafic ash tuffs** vary between massive and thinly laminated to thinly bedded (<0.3 to 10.0 cm). These tuffs are very fine grained, weather olive grey to olive green, and are dark greenish grey to dusky green on fresh surfaces. They generally contain less than 10 percent crystal fragments greater than 2.0 mm diameter and rare lapilli-size lithic fragments.

A 10 to 30 m thick bed consisting of **heterolithologic breccia** extends for about 800 m northwest of Bootleg Lake along the east side of Meridan Creek. It is characterized by abundant angular fragments of rhyolitic to dacitic composition (1 to 50 cm long) and subordinate intermediate to mafic fragments (<10 cm long) hosted in a plagioclase-rich intermediate matrix-supported framework.

3. Amisk Group Intrusions

The Amisk Group volcanic succession is intruded by a variety of syn- to post-volcanic mafic to acid dykes and sills.

a) Synvolcanic Minor Intrusions

The oldest dykes and sills are fine-grained mesocratic to melanocratic diorite and diabase generally less than 2 m wide, although widths of 5 m are not uncommon. Many of these dykes and sills display a distinctive centimetre-scale rhythmic banding, expressed by alternating grain size variations developed parallel to the dyke walls. The rythmically-banded dyke margins range from 0.1 to 0.5 m wide and grade abruptly into more massive interiors. Composite dykes and sills consisting of multiple intrusions of diorite and diabase are common. Contacts between the phases display a range of irregular sutured and intermingling contacts which suggest that emplacement of individual dykes occurred before earlier phases were completely solidified.

b) Post-volcanic Minor Intrusives

Post-volcanic diorite dykes are particularly prevalent between Bomber and Phantom Lakes. These dykes weather dark yellowish brown to greyish brown and are dark grey to greenish black on fresh surfaces. They are fine to medium grained and vary from equigranular to less commonly plagioclase porphyritic. The dykes are in places more than several tens of metres wide and extend several hundred metres along strike. A high volume of post-volcanic diorite dykes, tentatively considered to be pre-Missi in age, intrude the lower half of the Beaver Road assemblage and, in particular, the Myo Lake member. The rhyolitic to dacitic rocks of the Myo Lake member may have reacted in a more brittle manner than the surrounding mafic volcanics during this minor intrusive event, thereby providing a major stratigraphic control for the emplacement of the dioritic magmas.

4. Boundary Intrusions

The Boundary intrusions (Stockwell, 1946, 1960) are a series of elongated, lensoid and dyke-like bodies, ranging from ultramafic to felsic in composition, which intrude both Amisk and Missi Group rocks around the townsite of Flin Flon. The intrusions have been described in detail by Byers *et al.* (1965), Syme (1975), and Syme and Forrester (1977). Individual bodies are generally less than a few hundred metres long and lie in a north- to north-northwest-trending belt about 10 km long and 4 km wide. The largest intrusion in the belt crops out along the west side of Phantom Lake and underlies an area about 4 km^2. The Boundary intrusions are subdivided into three main petrological varieties: 1) an early mafic group, 2) a felsic group and 3) a younger olivine-bearing group (Syme and Forrester, 1977).

The **early mafic group** is the most prevalent variety and comprises porphyritic biotite-augite meladiorite, porhyritic hornblende meladiorite and minor highly altered "early" meta-pyroxenite. The mafic group is characterized by broad intrusion breccia envelopes and radiating dyke swarms peripheral to the intrusions. The meladiorite dykes commonly contain up to 25 percent subrounded volcanic, plutonic and older Boundary intrusion xenoliths which range from a few centimetres to a metre diameter. Several small semicircular features, less than 5 m diameter, containing a heterogeneous population of subrounded to rounded fragments in a clast-supported framework occur within the large Boundary intrusion at the north end of Phantom Lake. The highly-rounded nature of the clasts, and the heterogeneous clast population suggest these bodies represent highly fluidized "pipe breccias".

The **felsic group** is characterized by leucodioritic to granodioritic rocks containing less than 15 percent total mafic minerals (i.e. hornblende, biotite, and rare augite). This group represents less than 15 percent of the Boundary intrusions in the Douglas Lakes - Phantom Lake area and generally occur as small dykes and irregular-shaped intrusion breccias which appear to be younger than the mafic group.

The younger **olivine-bearing group** is composed of peridotite (wehrlite) and olivine gabbro members (Syme and Forester, 1977). Peridotite is primarily restricted to shoreline outcrops and several small islands at the north end of Phantom Lake. It appears to form a central zone to the largest Boundary intrusion in the area. Olivine gabbro occurs mainly as dykes which intrude both the older mafic group as well as the younger peridotites.

5. Boot Lake - Phantom Lake Intrusion

The Boot Lake - Phantom Lake intrusion is a multiphase body underlying the area between Phantom and Bootleg Lakes and extending for about 3.5 km southwards to Boot Lake. The petrology and structure of the intrusion has recently been described in detail by Galley and Franklin (1987) who introduced the term Boot Lake - Phantom Lake Complex[1] for the intrusion. They recognized a sequence of four main intrusive phases from mafic to progressively more felsic rocks (Figure 8).

Phase 1 is the most heterogeneous, consisting of gabbroic and dioritic rocks mainly in the western portion of the intrusion between Wekach, Bootleg and Arthur Lakes, and a small mass on the east shore of Boot Lake. The earliest rocks are medium-grained **melagabbros** forming a narrow discontinuous zone (<20 m wide) along the western periphery of the intrusion.

The melagabbros are sharply intruded by a suite of **leucogabbro, monzogabbro and anorthositic gabbro** as well as minor veinlets and irregular patches of **pyroxenite**. The youngest rocks of this phase are medium-grained **leucocratic diorite and quartz diorite**.

---

(1) In this report the term "intrusion" will be used instead of "complex".

Cognate xenoliths of gabbroic material are commonly present in the diorites and quartz diorites.

Phase 2 rocks occur outside of the present study area. They consist of fine-grained **hornblende - biotite porphyritic quartz monzodiorite** and minor **biotite porphyritic syenite** (Galley and Franklin, 1987).

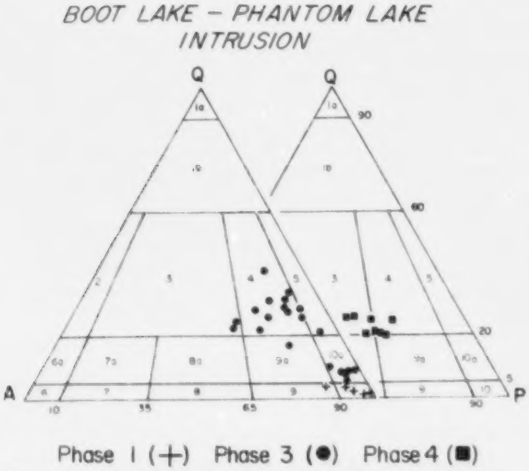


Figure 8 – Modal composition of rocks from the Boot Lake - Phantom Lake intrusion (based on 10 thin sections and 24 stained rock slabs). Subdivision names on Quartz - Alkali Feldspar - Plagioclase diagrams (after Streickeisen, 1976): 3, granite; 4, granodiorite; 5, tonalite; 8a, quartz-bearing monzonite; 9a, quartz-bearing monzodiorite; 10a, quartz diorite; 9, monzodiorite/monzogabbro; 10, diorite/gabbro.

Phase 3 rocks occur in two stocks of **plagioclase-porphyritic granodiorite** in the western portion of the intrusion and in a small mass around Boot Lake. The rocks vary from fine to medium grained, are light grey to medium light grey on fresh surfaces and weather pale yellowish orange to yellowish grey. Biotite and hornblende are present in about equal amounts and generally comprise less than 10 percent of the rock. Trace amounts of pyrite and chalcopryite occur as small blebs and narrow veinlets (<0.2 mm wide).

Phase 4 is represented by a large body of **microcline-porphyritic granite** underlying the northeastern part of the intrusion. The rocks, which are typically moderate orange pink on weathered surfaces and moderate reddish orange on fresh surfaces, vary from fine to medium grained and contain 5 to 15 percent euhedral microcline phenocrysts from 1 to 4 cm long (average 1.5 cm long). Quartz phenocrysts, from 1 to 2 mm diameter, comprise up to 15 percent of the rock while biotite generally forms less than 5 percent.

Contacts between the Phases 1 and 3 of the Boot Lake - Phantom Lake intrusion appear to be largely gradational to diffuse, however, Phase 4 rocks sharply intrude the earlier phases. The marginal zones of the younger phases commonly contain concentrations of cognate xenoliths derived from earlier phases of the intrusion. Some subrounded volcanic xenoliths occur in gabbroic and dioritic rocks of Phase 1 along the western margin of the intrusion and are particularly prevalent along the northern margin of the main body of Phase 4 between Phantom and Dion Lakes.

Stockwell (1946, 1960) and Byers *et al.* (1965) consider that the microcline-porphyritic granite (Phase 4) was intruded later than the surrounding granodiorites and diorites, and refer to it as the Kaminis or Phantom Lake granite. They considered these microcline-porphyritic phases to be related to the Boundary intrusions, and younger than the granodiorites and diorites in the region. On the other hand, Galley and Franklin (1987) report the presence of gabbroic xenoliths in the earliest phase of the intrusion, which they regard as derivatives of Boundary intrusions, implying that the Boot Lake - Phantom Lake intrusion entirely postdates the emplacement of the Boundary intrusions.

6. Late Dykes

Four suites of dykes intrude the Boot Lake - Phantom Lake intrusion and the surrounding volcanic rocks. From oldest to youngest they are:

1) Northeast-trending **diabase** and fine-grained **diorite** dykes which cut only Phases 1 and 3 in the western portion of the Boot Lake - Phantom Lake intrusion.
2) Light grey fine-grained **amphibole-plagioclase porphyritic granodiorite** to **tonalite** dykes form two dyke swarms; a) northwest-trending dykes in the Douglas Lake assemblage, and b) a less well-developed north-trending set intruding gabbros and diorites of the Boot Lake - Phantom Lake intrusion immediately east of Wekach Lake.
3) Moderate pink to light red **aplitic granite** dykes occur along the western and northern contact of the main mass of Phase 4 microcline porphyritic granite. These aplitic dykes are particularly abundant in the mafic volcanics immediately east of Dion Lake.
4) **Feldspar porphyritic granite** dykes, probably related to the Phase 4 microcline-porphyritic granite, are the youngest intrusives in the area and occur in a northwest to west-northwest dyke swarm intruding Phases 1 and 3 of the intrusion as well as in the volcanic rocks. Most of these dykes occur adjacent to the main porphyritic granite mass, however, similar dykes are observed in volcanic rocks 4.5 km northwest of the main body of Phase 4.

7. Structure and Metamorphism

a) Foliation and Lineation

The earliest foliation (S1) identified in the Douglas Lake - Phantom Lake area is a north- to north-northwest-trending well-developed schistosity dipping moderately to steeply northeast. Amygdules, pillows and volcanic clasts display variable degrees of flattening parallel to this foliation and commonly also define a linear fabric (L1) plunging moderately southeast. The S1/L1 foliation occurs entirely within Amisk volcanics and is best developed east of Bomber and Key Lakes. These early fabrics appear to be related to north- northwest-trending folds.

Between Boot and Bomber Lakes, the S1/L1 fabric is strongly overprinted by a slightly more westerly-trending southwest-dipping continuous cleavage and in this area the earlier S1/L1 fabric is rarely preserved. The S2 foliation varies between a moderate to well-developed schistosity and submylonitic to phyllonitic fabrics. Development of the S2 fabric is related to shearing which produced a broad northwest-trending zone of anastomosing shears extending from the east shore of Douglas Lake to Bootleg Lake.

The youngest foliation (S3) observed in the area is a shallow south-dipping millimetre-scale spaced cleavage. This late fabric is largely restricted to the northwest part of the area in a zone extending from the central part of Douglas Lake to the townsite of Creighton. Prominent southeast- and southwest-plunging linear fabrics (L3) occur as a result of intersecting S1/S3 and S2/S3 respectively. The S3 foliation has been attributed to regional contact strain within the Amisk volcanics during the emplacement of the Reynard Lake and Annabel Lake - Creighton Lake intrusions (Byers *et al.*, 1965), and appears to predate the emplacement of the Boundary and Boot Lake - Phantom Lake intrusions.

b) Folding

The Beaver Road anticline (Stockwell, 1946, 1960) is a major north-northwest-trending structure which folds Amisk Group volcanics in the Douglas Lake - Phantom Lake area. The axial surface trace of the structure extends from the south end of Flin Flon Lake to Phantom Lake where it is cut by a large Boundary intrusion. The fold has a steep east-dipping axial surface and a gentle southeast-plunging fold axis which are defined by the S1 schistosity and L1 stretching fabric respectively. Minor parasitic folds were not observed on either limb of the Beaver Road anticline.

c) Shearing and Faulting

Douglas Lake Structural Zone

Between Douglas and Bootleg Lakes a broad northwest-trending zone of anastomosing shears has affected the Amisk Group volcanics. This zone, termed here the Douglas Lake Structural Zone, appears to be largely truncated to the southeast by the Bootleg Lake - Phantom Lake intrusion which presumably postdates the shears. A few faults extend into the intrusion and may reflect later reactivation and propagation of the anastomosing shears. Penetrative fabrics (S2) occurring in this zone dip moderately to steeply southwest. Preliminary analysis of C-S fabrics, foliation deflection and vein offsets indicate an apparent sinistral displacement with a subhorizontal net movement. The structural zone can be divided into four principle shear/alteration systems:

1) variably chloritized shears developed along the east side of Douglas Lake (including the Newcor Mine shear),
2) chloritized - carbonatized shears along the central part of Douglas Lake,
3) a narrow zone of carbonitized and locally silicified shears along the west shore of Douglas Lake (including the Douglas Lake fault), and
4) a broad zone (*ca.* 200 m wide) of intensely silicified and deformed mafic pillow flows immediately east of Bootleg Lake.

Several other major northwest-trending faults in the area are probably related to the development of the Douglas Lake Structural Zone (e.g. Phantom Lake fault).

Cliff Lake - Ross Lake Fault System:

The Cliff Lake - Ross Lake Fault System forms a north-northwest-trending zone 4500 m wide and 12 km long through the greater Flin Flon area (Bailes and Syme, 1987; Galley and Franklin, 1987). Within the Douglas Lake - Phantom Lake area this major fault system consists of two principle components; 1) a set of easterly-dipping (*ca.* 60° to 80°) north- to northwest-trending sinistral faults, and 2) northeast-trending dextral faults dipping moderately northwest (*ca.* 55° to 70°). The more northerly-trending sinistral faults are the dominant set in the northern part of the area (e.g. Flin Flon Lake fault) whereas the northeast-trending dextral faults are more prevalent in the southern part of the area (eg. Rio fault, Henning-Maloney fault). Abutting relationships and relative movement directions indicate that the two fault sets were broadly contemporaneous and probably reflect a conjucate shear/fault system.

Dion Lake Structural Zone:

The Dion Lake Structural Zone (Galley and Franklin, 1987) forms an extensive (100 to 200 m wide) northeast-trending feature extending through the Dion Lake area. The zone is composed of closely-spaced branching shears displaying both dextral and sinistral displacements, although dextral movement appears dominant (Galley and Franklin, 1987). Original rock-types are difficult to determine within this zone due to intense hematite-quartz-ferrocarbonate-epidote alteration.

Syme and Forester (1977) considered the emplacement of the Boundary intrusions took place at the same time as the development of the Cliff Lake - Ross Lake fault system. The Boot Lake - Phantom Lake intrusion is also deformed by northeast-trending structures in the fault system (Galley and Franklin, 1987), implying that the Cliff Lake - Ross Lake fault system was developed during a protracted event involving plutonism, faulting/shearing and alteration.

d) Metamorphism

Amisk Group rocks in the Douglas Lake - Phantom Lake area possess metamorphic mineral assemblages characteristic of lower greenschist facies conditions. Basic volcanic rocks are essentially composed of mafic aggregates of chlorite, actinolite and epidote, while plagioclase phenocrysts are commonly saussuritized to white mica, epidote, albite, carbonate and quartz. This metamorphic mineral paragenesis appears to have been attained primarily during the north- to northwest-trending folding event responsible for the development of the S1 foliation. Emplacement of the earliest phases of the Boundary intrusions appears to have occurred during this north-northwest-trending folding and regional metamorphic event since preserved mafic to ultramafic rocks (eg. metapyroxenite) locally possess an S1 axial planar schistosity and lower greenschist facies metamorphic mineral assemblages.

The Boot Lake - Phantom Lake intrusion, which was emplaced after the main regional metamorphic event, appears to have undergone greenschist facies metamorphism. A contact metamorphic aureole up to 50 m wide composed of massive amphibolitized mafic volcanic rocks (e.g. hornblende-biotite- epidote-plagioclase), is developed along the western margin of the Boot Lake - Phantom lake intrusion. Amygdules in mafic flows immediately adjacent to the intrusion commonly contain a hornblende core mantled by an aggregate of plagioclase grains. Contact metamorphism and alteration of mafic volcanics along the northern contact of the Phase 4 microcline-porphyritic granite mass between Dion and Phantom Lakes has produced very flinty silicified and epidotized mafic volcanic rocks.

Later shearing and faulting in the Douglas - Phantom Lakes area largely occurred under lower greenschist facies conditions, since minimal retrogression of mineral assemblages has occurred along most structures.

8. Economic Geology

a) Base Metals

The Flin Flon - Snow Lake Belt hosts numerous base metal deposits of which the Flin Flon mine (62 million tonnes) is the largest Cu-Zn deposit in the region. Base metal mineralization in the Flin Flon - Amisk Lake area has been reviewed by Sangster (1972), Koo and Mossman (1975), Stauffer, Mukherjee amd Koo (1975), Coombe (1979), Price (1977), Bailes and Syme (1987), and Syme (1987). The deposits are classified as volcanogenic stratabound massive sulphide bodies of which most occur associated with rhyolite flows in dominantly basaltic portions of the Amisk Group (Syme, 1987).

Exploratory drilling in the Flin Flon area over the past decades has probably evaluated the majority of near surface conductors associated with these deposits. The identification of deeper exploration targets will increasingly depend on the application of physical volcanology and facies-mapping which can be applied to the recognition of favourable stratigraphic horizons in the Amisk Group. A primary objective of this revisional mapping program will be to establish both a stratigraphic and structural framework in order to accomplish this.

b) Gold

Gold occurrences are found throughout the Flin Flon - Amisk Lake area and have been systematically described on a deposit-scale as well as in a regional context by Pearson (1979, 1980, 1981, 1983, 1984), Pearson and Galley (1985), Pearson *et al.* (1986), Coombe (1984), and Galley and Franklin (1987). The majority of gold occurrences in the Douglas Lake - Phantom Lakes area display a strong structural control, particularly in relation to strike-slip structures of the Cliff Lake - Ross Lake fault system.

9. References

Alcock, F.J. (1923): Flin Flon map area, Manitoba and Saskatchewan; Geol. Surv. Can., Summ. Rep. 1922, ptC, p1-36.

Ambrose, J.W. (1936a): Progressive kinetic metamorphism in the Missi Series, near Flin Flon, Manitoba; Am. J. Sci. (5th ser.), v32, p257-286.

_________ (1936b): Structures in the Missi Series near Flin Flon, Manitoba; Trans. R. Soc. Can. (3rd ser.), v30, sec4, p81-98.

Ashton, K.E., Wilcox, K.H., Wheatley, K.J., Paul, D. and de Tombe, J. (1987): The Boundary Zone between the Flin flon Domain, Kisseynew gneisses and Hanson Lakes Block, northern Saskatchewan; *in* Summary of Investigations 197, Sask. Geol. Surv., Misc. Rep. 87-4, p131-134.

Bailes, A.H. and Syme, E.C. (1987): Geology of the Flin Flon-White Lake area; Man. Energy and Mines, Map GR 87-1-1.

Bruce, E.L. (1918): Amisk - Athapapuskow Lake District; Geol. Surv. Can., Mem. 105, 91p.

Byers, A.R., Kirkland, S.J.T., and Pearson, W.J. (1965): Geology and mineral deposits of the Flin Flon area, Saskatchewan; Sask. Dep. Miner. Resour., Rep. 62, 95p.

Coombe, W. (1979): Mineral deposits and regional metallogeny, southeastern Shield; *in* Summary of Investigations 1979, Sask. Geol. Surv., Misc. Rep. 79-10, p120-133.

_________ (1984): Gold in Saskatchewan; Sask. Energy Mines, Open File Rep. 84-1, 134p.

Galley, A.G. and Franklin, J.M. (1987): Geological setting of gold, copper, tungsten and molybdenum occurrences in the Phantom Lake region; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p115-124.

Gordon, T.M., Hunt, P.A., Loveridge, W.D., Bailes, A.H. and Syme, E.C. (1987): U-Pb Zircon ages from the Flin Flon and Kisseynew belts, Manitoba: chronology of Early Proterozoic crust formation; Geol. Assoc. Can./Mineral. Assoc. Can., Joint Annual Meeting, Program with abstract, v12, p48.

Heywood, W.W. (1966): Ledge Lake area, Manitoba and Saskatchewan, Geol. Surv. Can., Mem. 337.

Koo, J. and Mossman, D.J. (1975): Origin and metamorphism of the Flin Flon stratabound Cu-Zn sulphide deposit, Saskatchewan and Manitoba, Canada; Econ. Geol., v70, p48-62.

MacQuarrie, R. (1980): Absolute age of the Flin Flon deposit; (abstract), CIM Bull. v73, no820, p53.

McInnes, W. (1909): Explorations on the Churchill River and South Indian Lake; Geol. Surv. Can., Summ. Rep., 1908, p87-92.

Pearson, J.G. (1979): Flin Flon gold prospects: Douglas Lake - Wekach Lake area; 1:10 000 scale prelim. map *with* Summary of Investigations 1979, Sask. Geol. Surv., Misc. Rep. 79-10, p145-151.

________ (1980): Flin Flon gold project; *in* Summary of Investigations 1980, Sask. Geol. Surv., Misc. Rep. 80-4, p70-80.

________ (1981): Gold metallogenic studies: Phantom Lake - Schist Lake area; *in* Summary of Investigations 1981, Sask. Geol. Surv., Misc. Rep. 81-4, p97-100.

________ (1983): Gold metallogenic studies: Flin Flon - Amisk Lake area; *in* Summary of Investigations 1983, Sask. Geol. Surv., Misc. Rep. 83-4, p67-74.

________ (1984): Gold metallogenic studies, the Rio deposit; *in* Summary of Investigations 1984, Sask. Geol. Surv., Misc. Rep. 84-4, p123-126.

Pearson, J.G. and Galley, A.G. (1985): Gold deposits of the Flin Flon - Amisk Lake area; *in* Summary of Investigations 1985, Sask. Geol. Surv., Misc. Rep. 85-4, p83-89.

Pearson, J.G., MacDougall, F.H., and Galley, A.G. (1986): Geology and evolution of gold occurrences in the Flin Flon - Amisk Lake area, Saskatchewan; *in* Clark, L.A. (ed.), Gold in the Western Shield; Can. Inst. Min. Metall., Spec. Vol. 38, p399-411.

Price, D.P. (1977): Geology and economic potential of the Flin Flon - Snow Lake areas; Univ. Manit., Cent. Precam. Stud., Annu. Rep., 1977, p52-83.

Sangster, D.F. (1972): Isotopic studies of ore-leads in the Hanson Lake - Flin FLon - Snow Lake mineral belt, Saskatchewan and Manitoba; Can. J. Earth Sci., v9, no5, p500-513.

Stauffer, M.R. and Mukherjee, A. (1971): Superimposed deformations in the Missi meta-sedimentary rocks near Flin Flon, Manitoba; Can. J. Earth Sci., v8, no2, p217-242.

Stauffer, M.R., Mukherjee, A.C., and Koo, J. (1975): The Amisk Group: an Aphebian(?) island arc deposit; Can. J. Earth Sci., v12, no12, p2021-2035.

Stockwell, C.H. (1946): Flin Flon - Mandy area, Manitoba and Saskatchewan; Geol. Surv. Can., Pap. 46-14, 5p.

________ (1960): Flin Flon - Mandy, Manitoba and Saskatchewan; Geol. Surv. Can., Map 1078A (with marginal notes), scale 1:12 000.

Streickeisen, A. (1976): To each plutonic rock its proper name; Earth Sci. Rev., v12, p1-33.

Syme, E.C. (1975): Petrogenesis of the boundary intrusions, Flin Flon area, Saskatchewan - Manitoba; unpubl. M.Sc. thesis, Univ. Sask.

________ (1986): Schist Lake area, Athapapuskow Project; *in* Manitoba Energy and Mines, Report of Field Activities 1986, p36-42.

________ (1987): Athapapuskow Lake Project; *in* Manitoba Energy and Mines, Report of Field Activities 1987, p30-39.

________ (1988): Athapapuskow Lake Project; *in* Manitoba Energy and Mines, Report of Field Activities, 1988, p20-34.

Syme, E.C.; Bailes, A.H.; Gordon, T.M. and Hunt, P.A. (1987): U-Pb Zircon geochronology in the Flin Flon Belt: age of Amisk volcanism; *in* Manitoba Energy and Mines, Report of Field Activities, 1987, p105-107.

Syme, E.C. and Forester, R.W. (1977): Petrogenesis of the Boundary Intrusions in the Flin Flon area of Saskatchewan and Manitoba; Can. J. Earth Sci., v14, no3, p444-455.

Tanton, T.L. (1941a): Flin Flon, Saskatchewan and Manitoba; Geol. Surv. Can., Map 632A (with marginal notes), scale 1:63 360.

________ (1941b): Schist Lake, Saskatchewan - Manitoba; Geol. Surv. Can., Map 633A (with marginal notes), scale 1:63 360.

Tyrrell, J.B. (1902): Explorations in the northeastern portion of the district of Saskatchewan and adjacent parts of the district of Keewatin; Geol. Surv. Can., Ann. Rept., Vol. VIII, 1900, Rep. F, 48p.

Lithogeochemical Studies in the Flin Flon-Amisk Lake Area and Glennie Domain

B.R.Watters[1]

Watters, B.R. (1989): Lithogeochemical studies in the Flin Flon - Amisk Lake area and Glennie Domain; *in* **Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.**

Two project areas are described in this report: 1) Glennie Lake Domain and 2) the Flin Flon-Amisk Lake area. The work in the latter area is new and will be described first.

1. Flin Flon-Amisk Lake Area

During 1989 a new lithogeochemical project was initiated in collaboration with the detailed bedrock remapping program initiated this summer by D.J.Thomas in the Creighton-Flin Flon area (Thomas, this volume). The project is not intended to duplicate the fairly extensive geochemical database that already exists for parts of the area (Parslow, 1987; Gaskarth and Parslow, 1987) but will have the following objectives:

1. to provide support to the detailed bedrock remapping program, by permitting a more accurate geochemical definition of units;
2. to assist in the identification of tectonically-bounded blocks such as those recognized by Bailes and Syme (1987) and Syme (1988) in the adjacent Flin Flon-White Lake area of Manitoba;
3. to determine the geotectonic setting of the volcanogenic units;
4. to geochemically characterize sequences and units considered to be of importance with regard to base metal and gold mineralization.

Previous work in the Amisk Lake-Flin Flon area (Walker and Watters, 1982; Parslow, 1987; Gaskarth and Parslow, 1987) and in the Flin Flon-White Lake area of Manitoba (Bailes and Syme, 1987; Syme, 1988) suggests that the tectonic environment is complex and probably includes both oceanic crust and arc-related components. Determination of the genetic relationships between assemblages of different tectonic affinity will be a related objective.

Geochemical analyses will involve determination of major elements and an extensive suite of trace elements. The samples will be analyzed in part at the University of Regina and by commercial laboratories. Rare earth element data will be obtained for a limited suite of samples.

a) Progress to Date

Major and trace element data have been obtained for a small suite of samples from the Douglas-Phantom Lakes area (Thomas, this volume). These include mainly mafic volcanics and some intrusive units. Geochemical data for a representative set of these samples is given in Table 1.

The following observations are tentative. Classification of the volcanic rocks on the basis of covariation between SiO_2 and Zr/TiO_2 (Winchester and Floyd, 1977) suggests that a range of lava types were analyzed, from subalkaline basalt through andesite to dacite and rhyolite (Figure 1). This classification is inconsistent with field observations because, although some definite rhyolite units were sampled, the majority of samples were from pillowed mafic units. The same data plotted on a Zr/TiO_2 vs Nb/Y diagram (*ibid*) is more bimodal and consistent with the field observations (Thomas, this volume) in that the majority of samples are basaltic with a lesser suite of acid rocks (Figure 2).

The differences in classification resulting from the application of these two diagrams is significant in that it indicates considerable mobility of silica in some units and that geochemical classification of rocks from this area is likely to be unreliable unless the less mobile elements

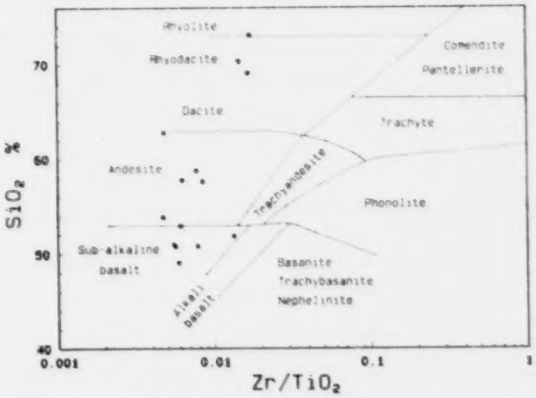


Figure 1 – Plot of SiO_2 vs. Zr/TiO_2 for metavolcanic rocks of the Douglas-Phantom Lakes area. Field boundaries after Winchester and Floyd (1977).

---

(1) Geology Department, University of Regina, Regina, Saskatchewan.

Table 1 – Selected geochemical analytical data for volcanic and intrusive rocks from the Douglas-Phantom Lakes area. Oxides are in percent, trace elements in ppm.

	259	*262*	*266*	*270*	*273*	*275*
SiO_2	48.10	77.10	47.70	66.70	49.50	68.40
TiO_2	.69	.15	.44	.47	.81	.37
Al_2O_3*	14.80	12.10	16.90	15.60	11.40	14.40
Fe_2O_3	15.20	.82	12.30	2.96	9.74	3.88
MnO	.20	.02	.19	.05	.15	.06
MgO	5.98	.31	4.57	1.26	12.20	1.51
CaO	4.51	2.19	12.40	2.49	6.93	3.18
Na_2O	3.22	3.23	1.66	5.11	2.51	3.44
K_2O	.36	2.10	.22	3.78	2.73	3.03
P_2O_5	.11	.03	.08	.20	.37	.09
l.o.i.	5.62	1.23	2.77	.77	2.39	1.23
Total	98.79	99.28	99.23	99.39	98.73	99.59
Rb	6	35	11	65	88	68
Sr	95	58	141	1280	672	224
Y	17	39	14	14	26	18
Zr	38	140	26	164	78	116
Nb	11	13	9	14	13	13
Pb	-	-	-	12	4	4
Th	-	-	-	3	-	2
Ni	10	-	18	-	279	8
Cu	175	65	160	127	78	36
Zn	149	50	82	62	76	53
Ba	66	207	82	1570	858	595
Co	42	8	39	10	38	10
Cr	48	28	37	6	842	66

* Total Iron as Fe2O3

8912-259	Mafic pillow lava; Douglas Lake
8912-262	Porphyritic rhyolite; Millrock Hill
8912-266	Mafic pillow lava; Green Street, Creighton
8912-270	Phantom Lake Granite; Phantom Lake area
8912-273	Boundary Intrusion; Phantom Lake area
8912-275	Bootleg Granodiorite; West Arm road

are used. Elements such as Zr, Ti, Nb and Y, as used in Figure 2, are generally regarded as relatively immobile.

Mafic volcanic rocks from the Douglas-Phantom Lakes area analyzed so far are tholeiitic (Figure 3) and show trace element features suggesting island arc affinities.

2. Glennie Domain

Lithogeochemical studies are being carried out in the Palf Lake, Gee Lake and Sadler Lake areas in support of field studies conducted by Thomas (1988) and Slimmon (1988 and this volume). Extensive suites of samples have been prepared for geochemical analysis and approximately 250 samples have been analyzed for all major and some trace elements. Further trace element determinations are in progress.

The following major rock units and types are being studied geochemically: Metavolcanics, Lueder Lake batholith, Arn Lake granite, Birkett Lake mafic intrusion, Hintz Lake diorite, Toro Lake tonalite, Hidden Bay pluton, St. John Lake member and Carroll Lake gneiss.

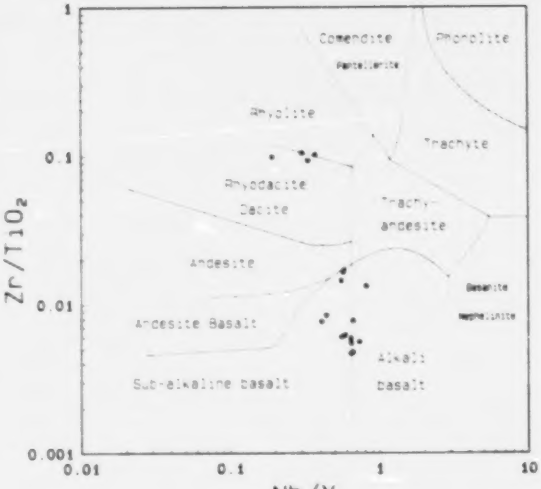


Figure 2 – Jensen cation plot for metavolcanic rocks of the Douglas-Phantom Lakes area. Field boundaries after Jensen (1976).

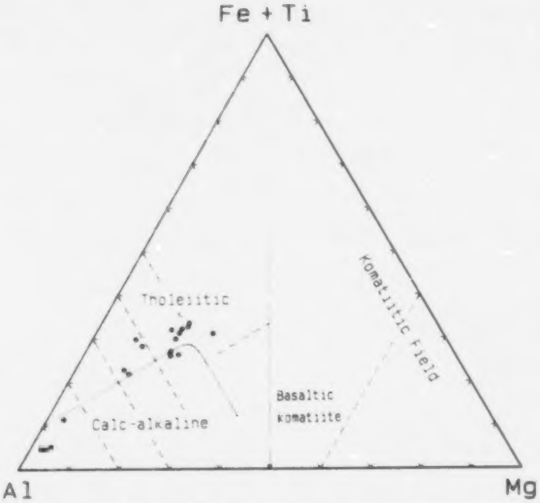


Figure 3 – Plot of Zr/TiO_2 vs. Nb/Y for metavolcanic rocks of the Douglas-Phantom Lakes area. Field boundaries after Winchester and Floyd (1977).

3. References

Bailes, A.H. and Syme, E.C. (1987): Geology of the Flin Flon - White Lake area; Man. Energy and Mines, Map GR 87-1-1.

Gaskarth, J.W. and Parslow, G.R. (1987): Proterozoic volcanism in the Flin Flon greenstone belt, east-central Saskatchewan, Canada; *in* Pharaoh, T.C., Beckinsale, R.D. and Rickard, D. (eds.), Geochemistry and Mineralization of Proterozoic Volcanic Suites, Geol. Soc. Spec. Pub. No. 33, p183-200.

Jensen, L.S. (1976): A new cation plot for classifying subalkalic volcanic rocks; Ont. Geol. Surv. Misc. Pap. 66.

Parslow, G.R. (1987): Lithogeochemical data from the East Amisk area of the Flin Flon - Snow Lake volcanic belt: Implications for mineral exploration; J. Geochem. Explor., v28, p133-148.

Slimmon, W.L. (1988): Bedrock geological mapping, Gee Lake area (part of NTS 63M-3 and -4); *in* Summary of Investigations 1988, Sask. Geol. Surv., p26-31.

Syme, E.C. (1988): Athapapuskow Lake Project; *in* Man. Energy and Mines, Report of field activities, 1988, p20-34.

Thomas, D.J. (1988): Bedrock geological mapping, Palf Lake area (part of NTS 63M-3 and -4 and 63L-13 and -14); *in* Summary of Investigations 1988, Sask. Geol. Surv., p20-25.

Walker, D. and Watters, B.R. (1982): Geochemistry of metavolcanic rocks, Amisk Lake West area; *in* Summary of Investigations 1982, Sask. Geol. Surv., p24-30.

Winchester, J.A. and Floyd, P.A. (1977): Geochemical discrimination of different magma series and their differentiation products using immobile elements; Chem. Geol., v20, p325-343.

The Development of Highly Strained Rocks in the Pelican Window during High-grade Metamorphism and Pervasive Anatexis

J.F. Lewry[1]*, R. Macdonald and M.R. Stauffer*[2]

Lewry, J.F., Macdonald, R and Stauffer, M.R., (1989): The development of highly strained rocks in the Pelican Window during high-grade metamorphism and pervasive anatexis; *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

Reinvestigation in the summer of 1988 of shoreline outcrops on Pelican and Mirond Lakes (Lewry and Macdonald, 1988) revealed the presence of rocks more highly strained than previously explicitly documented, and suggested that some re-evaluation of protolith interpretations was required.

This summer the authors of this paper conducted a more extensive examination of good shoreline and roadside exposures in the Pelican-Mirond-Jan Lakes region. The principal objectives were to identify the protoliths of the main mapped rock units in the Pelican Window (Figure 1), to categorize their strain state, seek kinematic shear-sense indicators related to the early phases of deformation, and evaluate the significance of such features within a regional context. The Pelican Window includes both the previously documented Sahli and MacMillan Point Archean granite inliers, and a package of highly strained gneisses, occupying a domal core region of the Hanson Lake Block between the underlying inliers and overlying Kisseynew Gneisses.

1. Re-evaluation of Lithological Units

On the basis of previous mapping (Macdonald, 1974, 1975; Sibbald, 1978; Macdonald and MacQuarrie, 1978; MacQuarrie, 1979) and our current observations, we recognize four informally designated lithological assemblages within the Pelican Window:

1. Archean granitoid inliers,
2. Pelitic gneisses,
3. Quartzofeldspathic gneisses and
4. Porphyroclastic gneisses

a) Archean Granitoid Inliers

The Sahli Granite and smaller MacMillan Point Granite occupy the lowest exposed structural levels in the core of the Pelican Window. Documented as reworked Archean basement inliers (Bell and Macdonald, 1982; Lewry *et al*., 1987; Craig, 1989), these inliers mainly comprise coarse-grained and variably retrogressed granulite-facies gneissic monzocharncockite. The Sahli Granite is cut by moderately deformed mafic dykes. A few outcrops of the Sahli inlier adjacent to its contact with structurally overlying rocks were re-examined, but no further interpretations were made.

b) Pelitic Gneisses

The pelitic gneisses comprise predominantly pelitic to psammopelitic biotite-garnet-sillimanite-(cordierite) gneisses derived from metasedimentary wackes, which generally mantle the Sahli Granite (Figure 1). These rocks are typically highly strained and contain large proportions of anatectic melt material. In this account the role of anatexis and strain, and the nature of mafic inclusions is described:

The Pelitic Gneisses are Highly Strained:

The pelitic gneisses have provided the best criteria for determining the structural sequence in the area. Locally well preserved early gneissic foliation (S1) is paralleled in places by primary layering (S0) (mostly defined by the more psammitic layers) and by anatectic melt *lits*. These elements are commonly transposed into a dominant S2 foliation which is axial planar to pervasive tight to isoclinal intrafolial D2 folds. Later generations of anatectic *lits* both parallel and cross-cut the S2 foliation. Open to tight folds (D3), locally with a good axial plane schistosity (S3) are common.

The amount of strain represented by the S1 and S2 fabrics is unquantifiable but probably very large. Early deformational events evidently occurred under high-grade metamorphic conditions, in rocks with a high biotite content and a high proportion of included melt. In such conditions, tectonic fabrics are likely to be essentially 'strain-insensitive', in the sense that the fabrics may not vary to any appreciable extent beyond certain levels of strain.

The Pelitic Gneisses are Generally Strongly Affected by Anatexis:

Typically 30-50 percent, and locally up to 70 percent of the rock is locally generated anatectic leucosome comprising concordant to semiconcordant seriate pegmatitic to leucogranitic lenses and discontinuous *lits*. In places

---

(1) Department of Geology, University of Regina
(2) Department of Geological Sciences, University of Saskatchewan

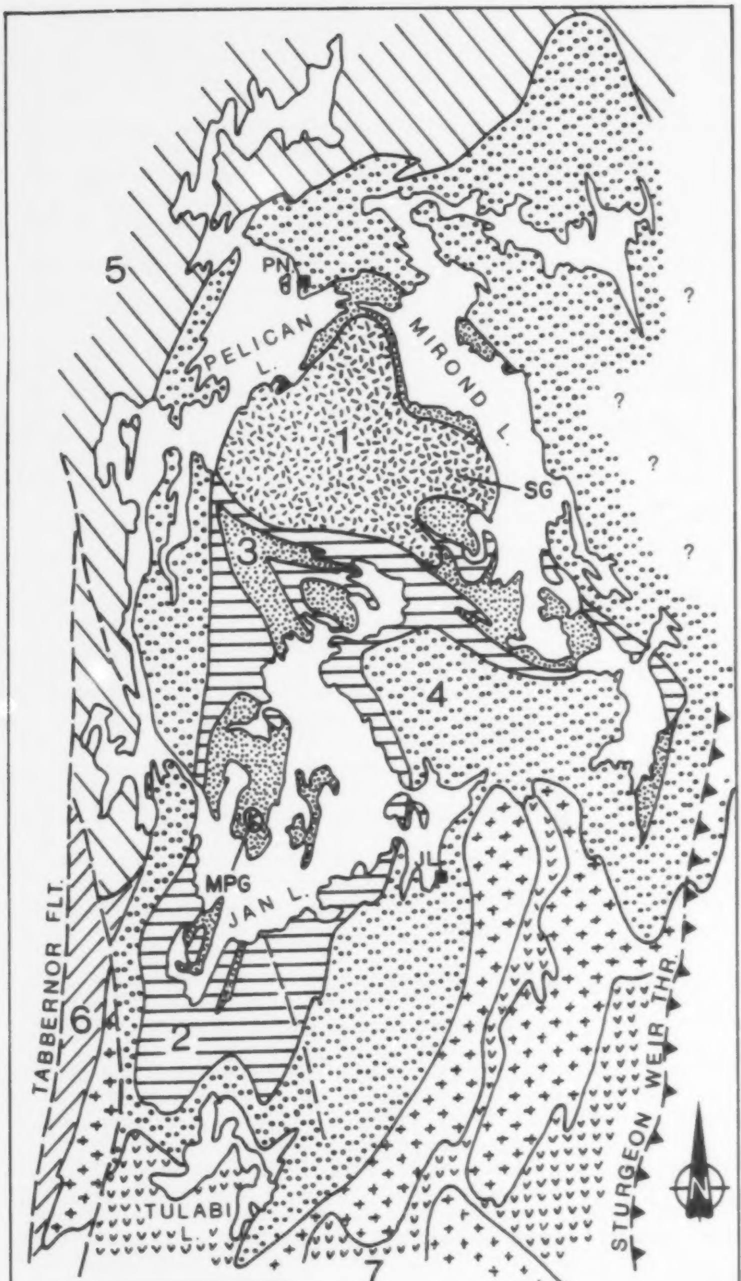


Figure 1 – General geology of the Pelican Window: 1 - Archean granitoid inliers. 2 - Pelitic gneiss assemblage. 3 - Quartzofeldspathic gneisses. 4 - Mixed hornblendic and porphyroclastic gneisses. 5 - Kisseynew Gneisses (high grade pelitic-psammopelitic). 6 - Lower grade metasediments along the Tabbernor Fault zone. 7 - Hanson Lake volcanics (low to medium grade) and plutons. PN - Pelican Narrows settlement. JL - Jan Lake resort. SG - Sahli Granite. MPG - MacMillan Point Granite.

the leucosome is wholly quartzofeldspathic to quartzose, but elsewhere fine sillimanite, cordierite and coarser biotite are present. This type of diatexite distinctively contains relatively few isolated feldspar megacrysts.

Early leucosome phases are generally accompanied by an ultramafic biotite-garnet restite melanosome in clearly-defined marginal selvages or less regular patches. Where pegmatitic leucosome comprises as much as 70 percent of the rock, the rest is almost wholly melanocratic restite, with little or no remaining paleosome.

The Pelitic Gneisses Contain Mafic Amphibolites:

Mafic amphibolites occur in semi-continuous layers a few centimetres to many metres thick, to isolated lensoid or ovoidal inclusions of various sizes. The more continuous layers parallel early foliation but are generally variably boudinaged and tightly to isoclinally folded. The amphibolites exhibit homogeneous medium- to coarse-grained metadiabasic or metagabbroic textures, but commonly display a prominent lighter grey green, but garnet-rich reaction rim against the pelitic gneisses.

c) Quartzofeldspathic Gneisses

Predominantly leucocratic quartzofeldspathic gneisses are complexly interlayered and interfolded with the pelitic gneisses, and locally lie in immediate contact with the Sahli Granite. Around the northern nose of the Sahli Granite and elsewhere the assemblage contains variably disrupted amphibolite sheets which Macdonald (1974, 1975, his unit QM) and Craig (1989) have interpreted as dykes or sills of diabase-gabbro, as confirmed by the present authors.

The quartzofeldspathic gneisses are leucotonalitic to granodioritic in paleosomal composition, generally comprising quartz and feldspar with less than 5 percent biotite. Macdonald (1974, 1975), MacQuarrie (1979) and Pyke (1966) mapped a number of subunits, based upon variations in colour (grey white to light grey pink), grain size (fine to medium grained) and degree of banding (unbanded to strongly and regularly banded). Some varieties contain regular quartz-feldspar segregation layers up to 1 or 2 cm thick spaced at intervals of about 5 to 15 cm. A major pinker and coarser subunit outcropping mainly between MacMillan Point and the Sahli Granite contains significant amounts of magnetite and is closer to monzogranite in composition.

Well-exposed sections of the quartzofeldspathic gneisses examined this summer on Jan, Pelican and Mirond Lakes include representatives of all sub-units described by the previous workers.

New criteria:

Clear indicators of protolith derivation and magnitude of strain are generally absent or equivocal. The following observations, however, lead us to the conclusion that most quartzofeldspathic gneisses are in fact very highly strained protomylonites and mylonites derived predominantly from plutonic protoliths.

i) In many outcrop sections, typical medium fine-grained gneisses of equivocal antecedents, can be traced across a decreasing strain gradient into demonstrably plutonic, medium coarse-grained tonalitic-granodioritic protoliths, which locally incorporate evident hornblende gneiss-amphibolite xenoliths of variable character. Some of these recognizable, less-strained protoliths are relatively uniform, but most incorporate a significant proportion of locally-generated pink leucogranitic/pegmatitic melt neosome, varying in morphology from pervasive diffuse patches throughout the paleosomal orthogneiss to discrete, relatively sharply bounded lenses, folia and irregular patches. In places this leucosome is accompanied by an irregularly developed complementary melanosome containing abundant magnetite and/or biotite. With increasing strain, such recognizable paleosome-leucosome-melanosome components were transposed into the main (S1 and/or S2) foliation, progressively forming finely banded and laminated 'candy-strip' gneisses (cf. Macdonald, 1974). Thus, much of the regular compositional and/or grain-size lamination and larger-scale interbanding of grey white tonalitic-granodioritic and pink granitic components may be interpreted as granitic melt leucosomes which were transposed into a strongly developed, locally mylonitic, S1/S2 tectonic foliation. Parts of the assemblage also show more or less regular, thin, and somewhat more mafic (generally biotitic) laminae. Some of these may be interpreted as transposed mafic restites marginal to granitic neosomal lits, others appear to represent xenolithic schlieren, but most are equivocal.

ii) In one locality, on the southwestern shore of Mirond Lake, thin concordant sheets of medium-grained, grey-white leucotonalitic gneiss, several centimetres to one metre thick, occur within dominant coarsely foliated and lineated Sahli granitic gneiss. These intercalations are indistinguishable from nearby typical tonalitic quartzofeldspathic gneisses. The sheets are strongly foliated but there is no indication that the intercalation is tectonic in origin; rather, features such as lateral continuity, sharp contacts and lack of strain gradients suggest that the leucotonalitic sheets represent intrusive apophyses into the Sahli gneiss.

iiii) The mineral composition of most of the paleosome, while not definitively precluding a metasedimentary origin, is more consistent with derivation from igneous protoliths. Quartz content is typically 30 to 40 percent and rarely appears to be more than 50 percent. Most paleosome contains dominant plagioclase feldspar. Potassium-feldspar is absent or a minor component. Biotite content is generally less then 10 percent. Garnet and sillimanite are rare. The sillimanite was observed only in neosomal melt veins. Although immature feldspathic metasediments of such character might conceivably derive from a proximal tonalitic-granodioritic provenance, such an occurrence is considered to be unlikely.

Assessment of Previous Criteria:

Previous workers considered the question of protoliths of the quartzofeldspathic gneisses. Pyke (1966) inclined to a plutonic origin for the magnetite-bearing unit, based upon isotope studies. Macdonald (1985) inclined toward a sedimentary origin for some of the subunits, not on the basis of their layered nature, but on account of their extensive uniformity and relatively fine grain size, the intimate association with the pelitic rocks, the presence of discontinuous calc-silicate layers and pods as well as magnetite, and an apparent crude stratigraphic symmetry of the units around the Sahli Granite (which is mirrored farther north around the Ukoop Lake and Manawan Lake domes). MacQuarrie (pers. comm.) considered a plutonic origin for some of the subunits.

The fine grain-size, as already shown, is an inconclusive factor, explainable by dynamic recrystallization under high strain.

The calc-silicates occur as lenses or boudin trains locally extending for several metres along strike. These may be interpreted as boudinaged sedimentary layers, implying that the enclosing quartzofeldspathic gneisses are also metasediments. However, identical or similar inclusions were observed locally within undoubted medium- to coarse-grained granodioritic orthogneisses. In some localities, moreover, calc-silicate pods are mixed up with a variety of mafic gneiss inclusions. Some of these may represent highly boudinaged intrusive sheets but elsewhere they display a variable composition and fabric, suggesting that they represent xenoliths. Some apparent 'calc-silicate' lenses proved on closer inspection more likely to be disrupted and metasomatized mafic dyke remnants.

The high magnetite content, either dispersed or in discontinuous concentrated 'seams' previously described in parts of the assemblage is in many places associated with anatectic melts and is possibly a solid phase product of partial anatexis. It cannot convincingly be ascribed to primary sedimentary heavy mineral concentration.

Conclusion:

It is concluded that most of the quartzofeldspathic gneisses proximal to the Sahli inlier in the Pelican-Mirond-Jan Lakes area are derived from initially coarser-grained leucotonalite to granodiorite and their anatectic derivatives, by a process of generally high but heterogeneous ductile strain.

Almost all features previously noted as possible indicators of paragneiss (psammite, meta-arkose) protoliths are either equivocal or can be interpreted as products of tectonometamorphic processes (i.e. anatexis, metamorphic segregation, transposition and strain variation). The possible presence of subordinate feldspathic metasediments is not precluded, but the weight of evidence suggests otherwise.

d) Mixed Hornblendic and Porphyroclastic Gneisses

The mixed hornblendic and porphyroclastic gneisses structurally overlie the pelitic and quartzofeldspathic gneiss assemblages, possibly forming a closed belt of variable width around the margins of the Pelican Window, and are particularly well displayed in the straight belt along the western side of Jan Lake and the Sandy Narrows Area. The assemblage includes the 'biotite gneiss with white feldspar megacrysts' (Macdonald, 1974), 'feldspathoblastic biotite gneisses' (Macdonald, 1975), 'feldspathoblastic and porphyroblastic gneisses', (Macdonald and MacQurrie, 1978), the 'Hornblende Gneiss Series' (Sibbald, 1978), 'blastoporphyritic intermediate to felsic pyroclastic rocks' (MacQuarrie, 1979) and, more generally 'hornblende-biotite gneisses' (Macdonald, 1981). Some of these rocks were previously identified as plutonic (e.g. Macdonald, 1974, 1975), but many were regarded by the earlier workers as deformed supracrustals, including volcanic rocks.

To the north and west, the assemblage is structurally overlain by dominantly pelitic-psammopelitic metasedimentary gneisses and plutonic rocks included within the Kisseynew Domain. To the south, they appear to structurally underlie lower-grade metavolcanics and plutons of the Hanson Lake area.

Observations this summer show that most rock-types can be traced across local strain gradients into recognizable protoliths or can be less confidently correlated with such protoliths on the basis of identifiable common features. These observations indicate that most of the assemblage was derived from variably migmatized plutonic protoliths. Four main subdivisions are recognized, broadly equivalent to the components of the 'Hornblende Gneiss Series' defined by Sibbald (1978):

Feldspar-porphyroclastic Gneisses:

The feldspar-porphyroclastic gneisses comprise biotite- and/or hornblende-bearing quartz-feldspar gneisses containing sparse to abundant plagioclase and/or potassium feldspar porphyroclasts. There is a marked gradational variation in grain-size, colour, mineral composition, size, shape and composition of porphyroclasts, degree of internal homogeneity and proportion of incorporated mafic/ultramafic gneiss inclusions. These rocks include both moderately deformed and protomylonitic to mylonitic varieties. A number of subunits are distinguished.

Medium to Coarse-grained Orthogneisses - The medium to coarse-grained orthogneisses, which form a subordinate part of the porphyroclastic gneiss assemblage, comprise mainly hornblende- and/or biotite-bearing tonalites to granodiorites ranging from uniform non-megacrystic or sparsely megacrystic, to variants containing abundant large plagioclase megacrysts. Some variants contain plentiful dull green relict igneous diopsidic pyroxene rimmed by hornblende. Xenoliths of layered and unlayered hornblende gneiss and amphibolite, ranging from small angular to rounded isolated blocks to larger tabular screens and inclusion trains are abundant locally. Calc-silicate xenoliths also occur in places.

Some of the orthogneisses display concordant white feldspathic leucosomal *lits* which commonly contain prominent isolated crystals and multicrystalline ultramafic clots of coarse black hornblende up to several centimetres in size. These are interpreted as resulting from pervasive *in situ* synkinematic anatexis and resultant hornblendic restite segregation.

The orthogneisses also generally incorporate a variable amount of apparently locally-derived pink granitic leucosome which includes diffusely to sharply bounded patches, thin *lits* and larger masses of leucogranite, irregular to tabular coarse pegmatite sheets and locally abundant large isolated potassium feldspar porphyroblasts. These early neosomal components are deformed, together with the host paleosome, by the earliest recognizable foliation and are thus easily distinguished from later post-tectonic granites and pegmatites of the Jan Lake suite.

The orthogneisses and early leucosomes are typically moderately to strongly foliated and there is a local outcrop-scale gradation into protomylonitic zones. Relatively coarse grained and moderately foliated variants typically display variable tectonic disruption and 'shredding' of pegmatitic material. Groundmass plagioclase crystals are incipiently rounded or beaded, and there is a similar rounding of larger plagioclase and potassium feldspar porphyroblasts.

Porphyroclastic Grey Gneisses - Variably porphyroclastic 'grey gneisses' are a major component of the assemblage. These rocks typically have a medium- to fine-grained, mid- to dark grey granoblastic to nematoblastic groundmass of quartz, plagioclase, biotite and/or hornblende. Plagioclase occurs in beads up to about one centimetre across and in lensoid to ovoidal, larger, and locally tailed plagioclase porphyroclasts up to several centimetres in size which locally form up to 10 to 20 percent of the rock.

The porphyroclastic grey gneisses are relatively homogeneous in many places, with an intense regular groundmass foliation. Elsewhere they are heterogeneous, with a streaky/lensoid to regular gneissic groundmass banding defined by variations in hornblende and/or biotite, colour, grain-size and porphyroclast content. In places, part of this banding is defined by intercalation of a fine-grained grey gneiss and somewhat coarser, more felsic *lits* displaying prominent hornblende blasts up to 5 mm or more in size, similar to the anatectic variants of the coarser orthogneisses. Where the hornblende porphyroblasts are well developed, the rock has a peppery appearance, which to the untutored eye may resemble crystal tuff.

Mafic gneiss inclusions, which locally form up to 50 percent or more of outcrop area, range from ovoidal to elongate lensoid blocks a few centimetres to over ten metres across, to semi-continuous boudinaged and isoclinally folded layers from less than one centimetre to soveral metres thick. Some small isolated blocks display sigmoidal tails extending into the groundmass foliation and are evidently rotated. More commonly, prominent asymmetric 'wrap-around' folding of the enclosing foliation is evident.

Many of the mafic inclusions are medium- to fine-grained, mesocratic to mafic, uniform, unlayered amphibolites, most if not all of which are probably disrupted dykes or sills. Uniform, medium- to coarse-grained, massive to moderately foliated metagabbro-metadiorite blocks, interpreted as mafic plutonic xenoliths, also occur locally. Elsewhere abundant banded to laminated hornblende gneisses may be metavolcanic inclusions.

Medium- to coarse-grained ultramafic inclusions range in size from small ovoidal to lensoid 'clots', to larger rolled inclusions up to a metre or more across. Although some of these may be plutonic xenoliths, most are tentatively interpreted as rolled 'restite' segregations.

In summary, many of the porphyroclastic grey gneisses share with the less deformed orthogneisses, such features as mineral composition, 'beading' of the smaller plagioclases, rounding of larger megacrysts, and mafic-ultramafic inclusions, and may in numerous locations be traced into evidently plutonic protoliths via strain gradients. It is concluded that most of the porphyroclastic grey gneisses are protomylonitic to mylonitic orthogneisses.

Potassium-feldspar Porphyroclastic Gneisses - Porphyroclastic gneisses rich in potassium feldspar are a significant but generally subordinate component of the porphyroclastic gneiss assemblage. They comprise light grey to pink, medium- to fine-grained, uniform, intensely foliated to laminated rocks containing sparse small potassium feldspar porphyroclasts, and somewhat coarser, commonly quartz-ribboned gneisses with abundant large, lensoid to rounded potassium feldspar porphyroclasts.

Such rocks commonly occur in continuous to discontinuous, centimetre- to metre-scale bands within the porphyroclastic grey gneisses but locally form units many tens of metres thick, some of which display internal strain gradation into megacrystic granite-granodiorite.

Other smaller porphyroclastic felsic gneiss units have been identified as protomylonitic to ultramylonitic equivalents of early pegmatite sheets. Although a meta-arkosic or felsic volcanic origin is not precluded for some of these units, the finer-grained felsic gneisses are generally interpreted as mylonitized leucogranites.

Banded Feldspathoclastic Gneisses - A large part of the assemblage comprises banded gneisses containing plagioclase beads and porphyroclasts, as well as abundant potassium feldspar porphyroclasts. We interpret these as being derived mainly from granodiorite/tonalite orthogneisses which have undergone variable anatexis, intrusion by later leucogranite and pegmatite, and high-strain transposition. Supracrustal components do not appear to be very significant.

Ultraporphyroclastic Biotite Gneisses - The porphyroclastic gneiss assemblage includes local zones of biotite-rich gneisses containing 30 percent or more large ovoidal white plagioclase porphyroclasts. It is presently unclear whether these derive from highly porphyritic plutonic rock or from diatexitic metasediments.

Banded Hornblende Gneisses:

Belts of regularly banded to finely laminated, medium- to fine-grained, felsic to ultramafic hornblende gneisses and amphibolites form a significant, but subordinate part of the assemblage. Constituent paleosomal rock types range from very leucocratic, plagioclase-rich felsic gneisses, through mesocratic laminated hornblendic gneisses to green black mafic to ultramafic amphibolites, which are interbanded on scales ranging from less than a centimetre to a few metres.

The banded hornblende gneisses were interpreted by previous workers as probable metavolcanics, volcanogenic metasediments and/or pyroclastics on the basis of regular banding and lamination, generally fine grain-size and apparent general regional strike continuity with metavolcanics in the Hanson Lake and Northern Lights Lodge area to the south.

Aside from layering, no conclusive primary volcanic features, such as volcanic clasts, pillows etc. were observed. The lamination and grain-size are at least in part a consequence of high strain. At least some of the felsic interlayers are transposed orthogneiss sheets. The more uniform mafic gneiss units are indistinguishable from the mafic 'dykes' occurring in the pelitic gneiss and quartzofeldspathic assemblages, and were so interpreted.

Features observed in an extensive outcrop at the north end of an island immediately west of Pelican Narrows settlement may indicate ductile strain of a layered ultramafic-mafic intrusion. This outcrop has the following features:

1) Semi-continuous zones of coarse-grained dark, green metapyroxenite occur in ovoid to lensoid blocks up to one metre across within fine-grained laminated mafic-ultramafic amphibolite. Strain gradients across the margins of the blocks show that the enclosing amphibolite is a protomylonitic derivative of metaproxenite.

2) A zone of disrupted coarse-grained 'metagabbro' shows similar strain gradation into enclosing laminated amphibolite.

3) Medium- to fine-grained felsic units consisting largely of plagioclase feldspar with up to ten percent diopside or possibly orthopyroxene might represent anorthosite/leuconorite layers.

Thus, while presently accepting the probability that most of the banded hornblende gneisses derive from metavolcanic protoliths, we caution that a significant proportion might be mylonitized intrusive rocks.

Pelitic Gneiss:

The assemblage includes minor intercalations of biotite-rich garnetiferous anatectic gneisses, locally containing visible sillimanite, which on the basis of mineralogy and leucosome/melanosome relations we generally interpret as probable pelitic metasediments.

Biotite-quartz-feldspar Gneiss:

The dominantly porphyroclastic assemblage includes subordinate units of relatively uniform, medium- to fine-grained, commonly biotite-poor but compositionally variable felsic gneisses, the protoliths of which are generally indeterminate. Some might derive from psammitic metasediments; others are probably orthogneisses.

Conclusion:

We conclude that most of the mixed hornblendic and porphyroclastic gneiss assemblage comprises strongly foliated to mylonitic orthogneisses, rather than paragneisses. Most rocks previously designated 'porphyroblastic' or 'feldspathoblastic' gneisses in the region derive, not from supracrustal (sedimentary or fragmental volcanic) protoliths, but from a variety of highly strained and generally anatectic tonalitic to granitic plutonic rocks. These include diatexitic mass melts generated from pelitic to psammopelitic metasediments, i.e. anatectic granitoids. Pelitic to psammitic components appear to constitute only a minor part of the assemblage. The fine-grained laminated amphibolites may be metavolcanic, or in part mylonitized mafic plutonics. The more uniform mafic gneisses are probably largely disrupted hypabyssal sheets.

2. Summary of Structural and Metamorphic Features

As indicated, most rocks in the Pelican Window above the Sahli Granite display a strong, locally protomylonitic to mylonitic foliation. This is deformed by upright to inclined northerly- (D3) and northeasterly- (D4) mesoscopic and regional folds.

The early foliation is generally a compound S1/S2 transposition fabric involving at least two phases of (probably) progressive deformation. In many pelitic, quartzofeldspathic and porphyroclastic gneiss outcrops, the S1 tectonic foliation is seen to be paralleled by early neosomal *lits*, by transposed primary compositional layering, and locally by concordant (probably transposed) mafic intrusive sheets. These fabric elements are tightly to isoclinally refolded and generally further transposed into the S2 axial plane foliation. The S2 transposition fabric is generally dominant and S1 surfaces can be distinguished only in F2 intrafolial fold hinges. The F2 minor folds are commonly pervasive and characterized by very large amplitude-to-wavelength ratios.

This early compound transposition foliation is commonly accompanied by a prominent and apparently broadly coeval stretching lineation, variously defined by elongate mineral aggregates, general mineral lineation, long axes of some porphyroclasts and, more commonly, elongation of pressure shadow tails around the last mentioned. Locally extreme boudinage of such features as the disrupted mafic dykes, and other structural features, suggest that development of the early planar/linear fabric involved very large bulk finite extensions. Widespread rotational shear-sense indicators, discussed below, demonstrate that overall strain involved a significant simple shear component.

Thus, the S1/S2 fabric development clearly involved very high and probably transpressive ductile strains, with general transposition of primary layering, intrusive sheets and neosomal melt fractions to produce 'straight' gneisses. The sequence of events indicated by relationships between early fabric elements, anatectic neosome, metamorphic mineral assemblages and textural features demonstrates that such deformation occurred in partially melted rocks during prevailing uppermost amphibolite to granulite facies metamorphic conditions. Thus, early high-strain features were probably accompanied by relatively coarse synkinematic dynamic recrystallization fabrics and extensively overprinted and obscured by subsequent comprehensive granoblastesis. Fabrics in many of the feldspar-rich quartzofeldspathic gneisses and porphyroclastic grey orthogneisses tend to be dominated by ovoidal groundmass plagioclase 'beads' and larger porphyroclasts. Prominent relict quartz ribboning and other manifestations of 'classic' mylonitic lamination are generally preserved only in the coarser quartz-rich protomylonitic to mylonitic anatectic melt products. Apart from this, few exposures possess typical mylonitic fabrics.

Our observations suggest, nonetheless, that most of the quartzofeldspathic and porphyroclastic gneisses are high temperature 'blastomylonites' *sensu lato* (protomylonite to ultramylonite). We base this interpretation on generally prevailing fine grain-size (despite locally evident strain gradation into medium- to coarse-grained orthogneiss and migmatite), mylonitic features seen in highly strained anatectic melts, and the character of the larger winged feldspar porphyroclasts which we will now describe.

a) Shear-Sense Indicators

Unambiguous and locally abundant shear-sense indicators which occur mainly in the porphyroclastic gneisses, include the following:

1) Winged feldspar porphyroclasts - Well preserved plagioclase and potassium feldspar delta porphyroclasts, in many places displaying highly rotated dynamic recrystallization tails, were observed in all lakeshore transects across the porphyroclastic gneisses and in roadside outcrops between the Jan Lake and Wintringham Lake turnoffs. In most cases, the indicated shear-sense could be clearly related to stretching lineation (movement) direction. More equivocal sigma porphyroclasts are also common.

2) Rotated and 'winged' mafic gneiss inclusions - Several localities display highly rotated mafic or ultramafic gneiss inclusions. Evidence of rotational shear sense variously includes asymmetric wrap-around folding of foliation in the enclosing mylonitic gneisses, deflection directions of the intensifying (S-plane) foliation on the margins of the inclusions and in several places the development of sigmoidal 'delta' tails extending from the inclusions themselves.

3) C-S fabric relations - Possible C-S fabrics were observed in a few places, mainly in 'shredded' pegmatite *lits* in protomylonitic granodioritic gneisses, but were not considered to be reliable shear sense indicators.

4) A number of other shear-sense indicators, such as extensional shear bands and 'back-rotated' boudins were also noted.

These data indicate an apparent general consistency of shear-sense and transport direction in different parts of the region. However, in view of the presently limited data set and evident problems of 'unfolding' about later regional folds, any conclusions regarding regional transport direction would be premature.

3. Regional Conclusions

It is acknowledged that most rocks in the Hanson Lake Block and Kisseynew Domain, and indeed throughout the Reindeer Zone, are highly deformed. Current observations suggest, however, that the entire lithostructural package lying between the Sahli-MacMillan basement inliers and the overlying Kisseynew Gneisses, was a locus of abnormally intense, though heterogeneous, ductile strain. This took place prior to the D3/D4 folding which produced the regional domal interference structure of the Pelican Window. A significant proportion of the constituent rocks can be regarded as protomylonitic, mylonitic and (rarely) ultramylonitic gneisses. It is unlikely that the relatively incompetent pelitic gneisses suffered less strain than the intercalated and overlying orthogneisses, particularly in view of their anatectic character.

This high-strain package developed, for the most part, under conditions of very high-grade metamorphism and pervasive anatexis. Under such conditions, very high strain rates and finite shear strains could be accommodated, without general development (or at least the retention) of 'classic' mylonitic fabrics. In some rocks a relatively coarse 'strain-insensitive' dynamic recrystallization fabric is likely to have developed.

Regional structural geometry demands that, prior to northerly (D3) and northeasterly (D4) refolding, this high-strain package above the Sahli-MacMillan inliers must have been a gently-dipping zone, probably at the sole of the Early Proterozoic allochthonous nappe pile. The magnitude of regional lateral displacement in this zone could have been of the order of tens or even hundreds of kilometres. It is presently unclear whether the Sahli and MacMillan Point Granites represent local exposure of autochthonous or para-autochthonous continental basement overridden along this high-strain sole zone, or whether the granites are part of an allochthonous basement thrust slice transported within the high-strain package.

The latter interpretation may be favoured by the presence of mafic dykes and sills which cut the Sahli Granite and much of the overlying presumed Early Proterozoic high strain package. These hypabyssals, although highly disrupted, persist with no evidence of abrupt truncation at least as far up the structural succession as the 'nose' of the Kisseynew Gneisses. If these dykes are consanguineous this suggests either that there is no abrupt major tectonic break at the basement/high strain package interface (possibly supporting the idea of cohesion between the inliers and the high strain package) or that the mafic sheets were emplaced relatively late in the development of the mylonitic gneisses. More detailed examination and possible dating of the dykes must be considered a high priority in future work.

The mixed hornblendic and porphyroclastic gneiss assemblage closely resembles the 'Nistowiak Gneisses' of southwestern Glennie Domain (e.g. Chiarenzelli *et al.*, 1987) in most lithostructural features, structural location and probable tectonic significance. On the other hand, while both occur at similar deep structural levels, they differ in that the Nistowiak Gneisses occur right at the junction with underlying Archean basement of the Iskwatikan window and comprise Archean as well as juvenile Early Proterozoic protoliths. In the Pelican Window, comparable gneisses are separated from Archean basement by intercalated pelitic metasediments and mylonitized non-porphyroblastic orthogneisses.

Possible regional continuity between the Nistowiak Gneisses and similar rocks of the Pelican Window is a matter of speculation. More locally, however, we suggest that there might well be a spatial and tectonic relationship between the high-strain package of the Pelican Window, the ductile Sturgeon-Weir 'thrust' zone, and high-strain zones in the adjoining lower-grade Flin

Flon Domain. The Sturgeon-Weir thrust appears to extend northwards towards southeastern extensions of the Pelican Window high-strain package (Ashton, 1987) and might represent a broadly related feature rooting in the package. Similarly, east-west-trending segments of refolded ductile-brittle shear zones in the northern part of the Flin Flon Domain appear to converge westwards towards the southeastern part of the Pelican Window and may again represent higher level listric splays off a deeper flat-lying detachment. Temporal and kinematic relationships between these features are presently unknown and require considerable further study and analysis.

In general, the results of this summer's work in the Pelican Window are broadly consistent with growing evidence (e.g. Delaney, 1988, and this volume; Slimmon, 1988, and this volume; Thomas, 1988; Lewry and Macdonald, 1988) that the Reindeer Zone largely comprises a zone of regional nappe development and crustal imbrication (Lewry *et al.*, in press).

4. References

Ashton, K.E. (1987): Preliminary geological map of the Kisseynew Gneisses between the Sturgeon Weir River and Kisseynew Lake, Saskatchewan; Geol. Surv. Can., Open File 1410.

Bell, K. and Macdonald, R. (1982): Geological calibration of the Canadian Shield in Saskatchewan; *in* Summary of Investigations 1982, Sask. Geol. Surv., Misc. Rep. 82-4, p17-22.

Chiarenzelli, J.R., Lewry, J.F. and Landon, M. (1987): Bedrock geology, Iskatikan Lake area: evidence for Hudsonian juxtaposition of Proterozoic and Archean rocks along a ductile detachment surface; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p45-51.

Craig, L.O. (1989): Geology of the Pelican Narrows area of east- central Saskatchewan; Unpublished Ph.D. thesis, University of Saskatchewan, 254p.

Delaney, G.D. (1988): Bedrock geological mapping, Brownell Lake area (part of NTS 63M-4 and 63L-13); *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p8-19.

Lewry, J.F. and Macdonald, R. (1988): Observations on deformation in the Glennie Domain and Hanson Lake Block; *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p35-41.

Lewry, J.F., Macdonald, R., Livesey, C., Meyer, M., Van Schmus, W.R. and Bickford, M.E. (1987): U-Pb geochronology of accreted terranes in the Trans-Hudson Orogen in northern Saskatchewan, Canada; *in* Pharaoh, T.C., Beckinsale, R.D. and Rickards, R., (eds.), Geochemistry and Mineralization of Proterozoic Volcanic Suites, Geol. Soc. Lond., Spec. Publ. 33, p147-166.

Lewry, J.F., Thomas, D.J., Chiarenzelli, J.R. and Macdonald, R. (in press): Structural relations in accreted terranes of the Trans-Hudson Orogen: telescoping in a collisonal regime?; *In* Lewry, J.F. and Stauffer, M.R., (eds.), The Early Proterozoic Trans-Hudson Orogen of North America; Geol. Assoc. Can., Spec. Pap.

Macdonald. R. (1974): Pelican Narrows (west) area; *in* Summary Report of Field Investigations by the Saskatchewan Geological Survey 1974; Sask. Dep. Miner. Resour., p30-37.

Macdonald, R. (1975): Semi-reconnaissance in three areas, Pelican Narrows area; *in* Summary Report of Field Investigations by the Saskatchewan Geological Survey 1975; Sask. Dep. Miner. Resour., p35-43.

Macdonald, R. (1981): Compilation bedrock geology, Pelican Narrows and Amisk Lake areas (NTS 63M, 63L, part of 63N and 63K); *in* Summary of Investigations 1981, Sask. Geol. Surv., Misc. Rep. 81-4, p16-23 (and accompanying 1:250,000 scale preliminary map).

Macdonald, R. and MacQuarrie R.R., (1978): Geological re-investigation mapping, Jan Lake area (part of NTS area 63M); *in* Summary of Investigations 1978, Sask. Geol. Surv., Misc. Rep. 78-10, p16-25.

MacQuarrie, R.R. (1979: Geological re-investigation mapping, Birch Portage South (NTS area 63L-15S); *in* Summary of Investigations 1979, Sask. Geol. Surv., Misc. Rep. 79-10, p29-38.

Pyke, M.W. (1966): The geology of the Pelican Narrows and Birch Portage aeras, Saskatchewan; Sask. Dep. Miner. Resour., Rep. 93, 68p

Sibbald, T.I.I. (1978): Geology of the Sandy Narrows (east) area; Sask. Dep. Miner. Resour., Rep. 170, 50p.

Slimmon, W.L. (1988): Bedrock geological mapping, Gee Lake area (part of NTS 63M-3 and -4); *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p26-31.

Thomas, D.J. (1988): Bedrock geological mapping, Palf Lake area (part of NTS 63M-3 and -4 and 63L-13 and -14); *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p20-25.

Base Metal Deposits and Geology of the Early Proterozoic Hanson Lake Metavolcanics

T.I.I. Sibbald

Sibbald, T.I.I. (1989): Base metal deposits and geology of the Early Proterozoic Hanson Lake Metavolcanics; *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report, 89-4.

The Hanson Lake area is located some 60 km west of Flin Flon at the southern margin of the Precambrian Shield. Geologically it lies within the Hanson Lake Block of the Reindeer Zone of the Trans-Hudson Orogen. The block comprises both Archean and Lower Proterozoic elements; the former represented by the charnockitic Sahli Granite and the MacMillan Point Granite and the latter by a mixed sequence of volcanic and sedimentary supracrustal rocks and a wide compositional range of intrusions. The metavolcanic rocks at Hanson Lake outcrop in the south of the block, where they structurally overlie granitoid migmatite gneisses of uncertain affinity, which form the cores of the Jackpine Lake and Tulabi Lake antiforms. Lead-lead (^{207}Pb/^{206}Pb) ages of 1870 and 1859 Ma have been obtained from two zircon fractions from the Jackpine Lake migmatites (Bickford *et al.*, 1988). The metavolcanics which range in composition from felsic to mafic, are overlain by metagreywackes in the eastern basin of Hanson Lake and intruded by bodies of felsic to ultramafic composition (Byers, 1957; Coleman *et al.*, 1970). Early Rb-Sr dating by Coleman (1970) had indicated an Archean age of 2375 ± 30 Ma for these rocks, however, new U-Pb zircon work by Van Schmus *et al.* (1987) has shown the metavolcanics to be Early Proterozoic (ca. 1888 ± 12 Ma) and coeval with the metavolcanics of the Amisk Group to the east (MacQuarrie, unpublished, Syme *et al.* 1987).

Supracrustal rocks in the Hanson Lake area are metamorphosed to lower to middle amphibolite grade with the lower amphibolite grade assemblages in the south. South of Hanson Lake the Precambrian Shield is overlain by Ordovician rocks; clean quartz-sandstones of the Winnipeg Formation and dolomites of the Red River Formation.

Renewed interest in this area stems from the 1988 discovery of the McIlvenna Bay copper-zinc deposit beneath Ordovician cover south of Hanson Lake . The deposit is presently estimated to contain 7.1 million tonnes of ore grading 1.1 percent Cu, 6.5 percent Zn, 27.3 g/t Ag and 0.55 g/t Au to the 500 m level in the main (#2) ore lens. About 5 km to the north the Western Nuclear Mine produced 147,300 tonnes of ore grading 5.83 percent Pb, 9.99 percent Zn and 0.51 percent Cu between 1967 and 1969.

The present investigation was designed to improve understanding of the geological environment of these base metal deposits through 1:20,000 scale mapping of the exposed Shield area surrounding the Western Nuclear Mine and logging of representative cores from the McIlvenna Bay deposit.

Previous geological mapping of the area was undertaken by Byers (1957) at 1:31,680 scale and by Coleman *et al.* (1970) at 1:15,840 scale. The current mapping has not changed the distribution of the major lithological units, however, significant differences in interpretation have been made, particularly with respect to the nature of the felsic rocks.

1. Description of Rock Types

The exposed volcanic edifice around the Western Nuclear Mine comprises predominant dacitic and rhyolitic lavas, pyroclastics and/or epiclastics overlain successively by compositionally mixed volcanics and greywackes. Subvolcanic quartz feldspar porphyry plutons intrude the felsic volcanics and gabbroic sheets intrude the overlying mixed sequence.

a) Dacitic Volcanics

Dacitic volcanics are represented by a monotonous sequence of grey, fine-grained felsic schists. Layering, typically conspicuously absent on a small scale, is restricted to large scale cryptic compositional variations. In many outcrops the dacites are recognizably fragmental. The fragments are commonly more felsic than the matrix. Lapilli sized fragmentals predominate over coarser tuff breccias. The recognition of fragments is generally equivocal and inferred from diffuse small scale compositional variations. If these rocks are correctly interpreted, then a significant proportion of the dacite pile comprises poorly stratified pyroclastics and/or epiclastics. Relatively homogeneous feldsparphyric units characterized by 1 to 3 mm long subhedral to euhedral feldspar laths in a fine-grained matrix are locally mappable, particularly east of the Western Nuclear Mine. They may represent flow rocks.

The dacites contain quartz and feldspar, as scattered phenocrysts and matrix minerals, biotite ± garnet ± muscovite (sericite) ± chlorite. Quartz phenocrysts up to 5 mm in diameter are irridescent blue. Mafic minerals seldom comprise more than 10 percent of the rock. Biotite typically occurs as spotty aggregates which weather recessively. Garnet forms subhedral pink porpyhyroblasts up to 1 cm in diameter.

Dacitic rocks north and east of Bluebird Island are locally and irregularly calcareous, containing amphibole and poosibly diopside. The calcareous zones typically weather recessively lending outcrop surfaces a ribbed and/or irregularly pitted morphology. Calc-silicate layers and lenses formed by massive amphibolites of mafic to ultramafic composition and diopside-amphibole ± garnet ± calcite rich units occur sporadically within the calcareous dacites and are locally mappable. Their origin is uncertain, but could be due in part to magnesium metasomatism associated with hydrothermal activity.

b) Rhyolitic Volcanics

Rhyolitic volcanics and related rocks, interpreted to form a rhyolite dome, occupy the central part of the mapped area from Agnew Bay in the north through Parrex Bay to the entrance of McIlvenna Bay in the south. Previous mapping by Byers (1957) and Coleman *et al.* (1970) reported felsic rocks in this area respectively as intrusive quartz feldspar porphyry and, as predominantly extrusive ignimbritic soda-rhyolite porphyry flows mixed with some near surface intrusions. The present mapping distinguishes areas of rhyolitic volcanics from intrusive quartz feldspar porphyry. This distinction is clearly of importance in identifying potential localities for volcanogenic massive sulphide mineralization.

The rhyolitic volcanics are light grey to white, fine-grained and poorly layered to unlayered rocks characterized by irridescent blue quartz phenocrysts up to 5 mm in diameter. Breccia structure present in many outcrops is indicated by irregular blocks of quartzphyric aphanitic porcellaneous 'rhyolite' centimetres to 10's of centimetres across set in a matrix of quartz feldsparphyric sericite schist. The blocks may show fine millimetre-scale contorted lamination interpreted as flow banding. Tectonic deformation inside the blocks appears to be weak relative to that in the surrounding sericite schist matrix. Exotic fragments of more mafic composition occur rarely within the rhyolitic breccias.

Quartz eye sericite schists outcrop on the western shore at the entrance of McIlvenna Bay and at the south end of Agnew Bay. In the latter location they are interlayered with typical quartzphyric rhyolite and pink aphyric cherty, possibly silicified 'rhyolite'. The sericite schists form unlayered units. They may represent hydrothermally altered rhyolites or poorly stratified detritus weathered from rhyolite, which have undergone preferential shearing as a result of argillization and/or chemical and mechanical breakdown during weathering.

Quartzphyric rhyolites occurring in the channel at the souteast corner and the south end of Agnew Bay are sporadically replaced by mixtures of calc-silicate minerals (diopside, amphibole, epidote), and carbonate. Progressive replacement has led to the development of blue quartz-eye calc-silicate rocks. Brecciation unusually appears to accompany this process. In parts of the same outcrop areas, quartz eyes are obscured within a fine-grained cherty matrix, possibly as a result of silicification.

c) Mixed Volcanics

The mixed volcanics capping the rhyolite dome are of variable felsic to mafic composition. Fine-grained homogeneous amphibolites (metabasalts) outcrop along the northwest side of a chain of islands north of the entrance of McIlvenna Bay. These amphibolites are typically veined by yellow buff medium-grained granular carbonate as are the more easterly-lying volcanics of felsic (dacitic) to intermediate composition. In the latter carbonate veining is so intense locally that a pseudo-breccia is formed in which elongate, grey, massive, fine-grained 'dacite' relicts are set in a recessively weathering carbonate matrix.

Farther north the mafic rocks are nowhere exposed and carbonate veining appears to die out. There the mixed volcanic unit forms a prominent topographic linear of high ground bounding the eastern basin of Hanson Lake and comprises possible dacitic to andesitic flow rocks and fragmentals. These are typically grey weathering, medium- to fine-grained and poorly layered to unlayered feldsparphyric rocks containing from 10 to 20 percent mafic minerals. Lapilli sized fragments of both mafic and felsic compositions are identifiable in places. Feldspars are typically lath shaped, up to 5 mm long and locally ophitic textured. Blue quartz eyes from 2 to 3 mm in diameter occur rarely. Mafic minerals are hornblende and biotite; the former occurs as euhedral 'phenocrysts' in weakly deformed areas, but is more typically altered to biotite aggregates which lend the rock a spotted pock-weathering appearance.

d) Greywacke

Greywacke which is interlayered with the mixed volcanics along their eastern exposed margin, is a grey black, fine-grained quartzofeldspathic rock. It is delicately layered on a 1 to 100 cm scale. Garnets up to 5 mm in diameter comprise as much as 25 percent of some layers and other layers are strongly hornblendic.

e) Quartz Feldspar Porphyry

Quartz feldspar porphyry intrudes the felsic volcanics with sharply defined contacts, as irregular stock-like masses of several square kilometres extent and as sheets ranging down in size to a few metres wide. Although essentially similar, individual porphyry masses show variations in phenocryst size and mineral content. The rock is grey, inequigranular, homogeneous and weakly foliated to unfoliated and contains subhedral quartz and feldspar phenocrysts set in a medium- to fine-grained felsic matrix. Quartz phenocrysts typically much less abundant than feldspar, range up to 7.5 mm in diameter in contrast to feldspar laths which are seldom more than 2 to 3 mm long. Many of the quartz eyes are irridescent blue. Biotite and chlorite comprise up to 10 percent of the rock and muscovite (sericite) is locally important in sheared porphyry.

f) Mafic Intrusives

Mafic intrusives, possibly sills from a major diorite-gabbro body exposed along the southern and eastern shorelines of Hanson Lake, are represented by dark green, fine- to coarse-grained, homogeneous and weakly foliated to unfoliated amphibolites. Hornblende and plagioclase in essentially equal proportions are principal component minerals and garnet and/or biotite are rare minor constituents.

2. Structural Geology

Interpretation of the structural geology is hindered by the virtual absence of small scale compositional layering in all rocks except the greywackes. Foliation (schistosity) trends uniformly north and dips steeply east or west throughout the area. Major lithological volcanic units appear to trend sub-parallel to the regional foliation and there is no sign of large scale folding resulting in the repetition of units.

Schistosity is variably developed both on a regional and local scale. To the west of the Western Nuclear Mine, the dacitic volcanics are strongly foliated, and in places immediately west of the 'mine porphyry' fabrics are submylonitic. By contrast, volcanics to the east are significantly less deformed. Porphyry intrusions show weak or no sign of significant deformation, in contrast to the surrounding volcanics.

Linear structures including rodding, minor fold axes (of layering and quartz veins) and fragment elongation typically plunge gently in the dacitic volcanics west of the Western Nuclear Mine and boudinage axes plunge steeply north. In volcanics east of the Mine fold axes plunge moderately to steeply north as does the axis of elongation of fragments.

3. McIlvenna Bay Deposit

The McIlvenna Bay copper-zinc deposit is hosted by metavolcanics beneath a 15 m thick cover of Ordovician sandstones and dolomites. The deposit comprises three stratiform lenses of massive sulphides which dip steeply northeast. The main #2 ore lens plunges moderately to the north.

a) Footwall Rocks

The massive sulphide lenses and stringer sulphide zones are underlain by medium-grained, well laminated quartz muscovite (sericite) schists (Table 1). Lamination, on a millimetre to centimetre scale, is marked by alternating siliceous (chert) and micaceous layers. Darker layers with biotite and dark coloured graphitic foliae and layers occur sporadically. Below this are generally poorly cryptically layered, medium-grained quartz muscovite schists which lack cherty laminations. Blue quartz eyes up to 5 mm diameter are common in these homogeneous quartz muscovite schists and are also found locally in the overlying well laminated sequence.

b) Hanging Wall Rocks

Table 1 - Local stratigraphy at McIlvenna Bay copper-zinc deposit. Thickness estimates based on data selected from diamond drill holes: HA-8-8, 8-21, 9-30 and 9-33.

Approximate Thickness (m)	*Volcanic/Sedimentary Unit*	*Intrusive Unit*
–	Mixed felsic-mafic volcanics	
0.1-23	Upper BIF - mixed oxide-silicate- sulphide facies	
50-70	Massive mafic volcanics - amphibolite (meta basalt)	
3-5	Lower BIF - mixed oxide-silicate- sulphide facies	
35	Mixed mafic-felsic volcanics	Mafic sills
2-6	Laminated quartz muscovite schist- chert-feldsparphyric tuff	↑
7-50	Mineralized zone - massive sulphide lenses and stringer zones	Mafic dykes
25-55	Laminated quartz muscovite schist- chert	
	Cryptically layered quartz muscovite schists	↓

The mineralized zone is overlain by a **well laminated felsic unit** a few metres thick, characterized by fine-grained siliceous (chert) and medium-grained micaceous and feldsparphyric layers. The feldsparphyric layers contain subhedral feldspar crystals up to 5 mm in diameter set in a finer-grained felsic matrix containing up to 25 percent biotite, and are interpreted as dacitic crystal tuffs.

The hanging wall felsic unit changes sharply into a **mixed felsic-mafic unit** in which the mafic component is dominant. Interlayering is on a scale of centimetres to tens of centimetres. Mafic bands typically comprise fine-grained, poorly layered to unlayered amphibolites, whereas felsic bands are generally finely laminated, 'cherty' to micaceous and in part feldsparphyric.

A **lower banded iron formation** of mixed oxide-silicate-sulphide facies overlies the felsic-mafic unit. A thin fractured and brecciated graphitic interval occurs at the base. The iron formation is well layered on a millimetre to centimetre scale with mixed quartz-magnetite, garnet-amphibole-epidote and pyrrhotite-rich sections. It is typically fine-grained, although garnets form porphyroblasts up to 5 mm in diameter. In places the layering is chaotically disjointed in a manner suggesting slumping.

A **massive mafic unit** comprising fine-grained, compositionally uniform, weakly foliated amphibolite (metabasalt) caps the iron formation. The unit is in part epidotized and towards the base cut by medium-grained, granular, white carbonate veins. Also towards the base, the unit becomes weakly layered and garnet is present in some layers.

An overlying **upper banded iron formation**, which is to some extent interlayered with the upper part of the mafic unit, is of mixed facies and resembles the lower iron formation. As the unit is of markedly differing thickness in the two drill holes in which it was examined, it may form a less predictable marker unit. A **mixed felsic to mafic volcanic sequence** overlies the upper iron formation.

Mafic rocks appear to be present as intrusions in both the mafic-felsic unit of mixed volcanics and the mineralized zone and footwall. In the mafic-felsic unit, medium-grained, weakly foliated to massive, weakly hornblende-porphyroblastic amphibolite is present in several, though not all holes at the same stratigraphic level suggesting the presence of a sill-like mafic body. In the mineralized zone and footwall, up to 1 m thick, fine-grained, unfoliated, homogeneous "barren" amphibolites, that cut massive and stringer sulphide mineralization, are clearly mafic dykes.

c) Mineralization

Many of the classic features of volcanogenic massive sulphide deposits (Lydon, 1984) are exhibited by the mineralization and altered host rocks at McIlvenna Bay. Mineralization occurs as massive sulphides in discrete lenses and as underlying stringer sulphide zones. The massive sulphide lenses comprise essentially unlayered pyrite-sphalerite-chalcopyrite. The pyrite is typically coarse-grained and the sphalerite and chalcopyrite occur interstitially with minor carbonate. Angular, dark green chlorite fragments and rounded quartzs blebs are typical inclusions. The underlying stringer zones are typified by copper and iron sulphide concentrations parallel to and cross-cutting schistosity. Adjacent to the sulphides, dark green chlorite coats slickenslided fracture surfaces. Chlorite is also 'disseminated' in adjacent host rocks.

Felsic schists which host the mineralization are grey, poorly layered, medium-grained quartz muscovite chlorite schists with andalusite in places. Andalusite is present as pale pink porphyroblasts up to 1 cm across in some sections and blue quartz eyes are recognizable locally. The felsic schists appear to have been derived by processes of alteration, including chloritization, silicification and argillization, from the laminated quartz muscovite schists of the footwall, which show a transitional contact.

4. Western Nuclear Deposit

The Western Nuclear Deposit is located beneath Hanson Lake about 200 m east of the mine site . A description of deposit geology based on drill core (Byers, 1957) indicates the presence of a vertically dipping, northerly-trending zone of zinc-lead-copper mineralization in interlayered dacite, mafic tuff, quartz sericite fuchsite schist and quartz feldspar porphyry.The banded quartz sericite fuchsite schists are the immediate host to pyrite-pyrrhotite-sphalerite-galena-chalcopyrite 'stringer' mineralization. These schists abut the massive sulphide zone, which comprises sphalerite-galena and variable amounts of arsenopyrite-pyrite-chalcopyrite-pyrrhotite, on the east side. The sequence is presumed to young to the east irrespective of the spatial relationship between 'stringer' and possibly related massive sulphide mineralization. Coleman *et al.* (1970) report that the deposit occurs between metasomatized felsic volcanics to the west and rhyolite porphyry to the east. The metasomatized rocks are identified by abundant coarse amphibole, biotite, garnet, diopside and in places green (fuchsite) mica.

5. Discussion

Comparison of the local stratigraphy at the McIlvenna Bay deposit with that in exposed Shield at Hanson Lake indicates mineralization occurring at the end of a major period of rhyolite volcanism. The mineralized horizon is traceable through the mapped area to the northwest of the chain of islands at the mouth of McIlvenna Bay on which the hanging wall massive mafic unit and overlying mixed felsic to mafic volcanics are exposed. The horizon trends northward through the channel at the southeast end of Agnew Bay and continues beyond the confines of the presently mapped area up the east side of the Bay. The horizon is probably cut by quartz feldspar porphyry and mafic intrusions.

The mineralization of the Western Nuclear Mine appears to be associated with an earlier cycle of rhyolite volcanism, manifested by the quartz sericite fuchsite schists of the mine zone. North of the mine site the mine horizon is cut off by a major quartz feldspar porphyry intrusion. About 3 km farther north, a sequence of mixed quartz muscovite schists and aphyric and quartzphyric rhyolites may represent the extension of the mine horizon beyond the intrusion. This rhyolitic sequence is both overlain (to the east) and underlain (to the west) by dacitic volcanics. The underlying dacites are calcareous and interlayered with calc-silicate rocks and amphibolites, which are possible equivalents of Coleman *et al.'s* (1970) metasomatic rocks to the west of the Western Nuclear deposit. The mine horizon trends northward out of the map area up Agnew Bay.

Mineralization at both McIlvenna Bay and the Western Nuclear Mine occurs in finely interlayered quartz muscovite (sericite) schists and cherts, atypical of the area as a whole. These sequences are interpreted as subaqueously deposited sediments derived from the weathering of adjacent 'rhyolite' volcanics (quartz muscovite schists) and from chemical precipitation of silica (cherts) resulting from hydrothermal activity. Their finely laminated character is compatible with a hiatus in volcanism, which in the case of the McIlvenna Bay deposit, coincides broadly with the end of rhyolite volcanism and onset of mafic volcanic activity.

The mineralized horizons, particularly their extensions to the north, clearly merit continued exploration. A third and earlier cycle of rhyolite volcanism marked by a thin zone to the west of the Western Nuclear Mine may also be worthy of investigation. The zone outcorps at the south end of Bertrum Bay as fine-grained quartz muscovite schists and blue quartzphyric rhyolite containing fuchsite.

6. References

Bickford, M.E., Collerson, K.D. and Lewry, J.F. (1988): U-Pb geochronology and isotopic studies of the Trans-Hudson Orogen in Saskatchewan; *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p112-116.

Byers, A.R. (1957): Geology and mineral deposits of the Hanson Lake area, Saskatchewan; Sask. Dep. Miner. Resour., Rep. 30, 47p.

Coleman, L.C. (1970): Rb/Sr isochrons for some Precambrian rocks in the Hanson Lake area, Saskatchewan: Can. J. Earth Sci., v7, p338-345.

Coleman, L.C., Gaskarth, J.W. and Smith, J.R. (1970): Geology and geochemistry of the Hanson Lake area, Saskatchewan; Sask. Resear. Coun., Geol. Div., Rep. 10, 156p.

Lydon, J.W. (1984): Volcanogenic massive sulphide deposits; Part 1: a descriptive model; Geoscience Canada, v11, no4.

Syme, E.C., Bailes, A.H., Gordon, T.M. and Hunt, P.A. (1987): GS-19 U-Pb zircon geochronology in the Flin Flon Belt: age of Amisk volcanism; in Manitoba Department of Energy and Mines, Report of Field Activities 1987, p105-106.

Van Schmus, W.R., Bickford, M.E., Lewry, J.F. and Macdonald, R. (1987): U-Pb geochronology in the Trans-Hudson Orogen, Northern Saskatchewan, Canada; Can. J. Earth Sci., 24, p407-424

Beryl Pegmatites in the Jan Lake Area, NTS 63L and NTS 63M

D.G. MacDougall

MacDougall, D.G. (1989): Beryl pegmatites in the Jan Lake area, NTS 63L and 63M; *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

Beryl in granite pegmatites[1] in NTS areas 63L and 63M (Figure 1) has been recorded by Radcliffe (1964), Pyke (1966), Padgham (1968), Coleman *et al* (1970), Macdonald & Posehn (1976) and Scott (1981). Pegmatite on the west shore of Attree Lake on the Sturgeon-weir River is reported to be beryliferous (Bennett, pers. comm.)

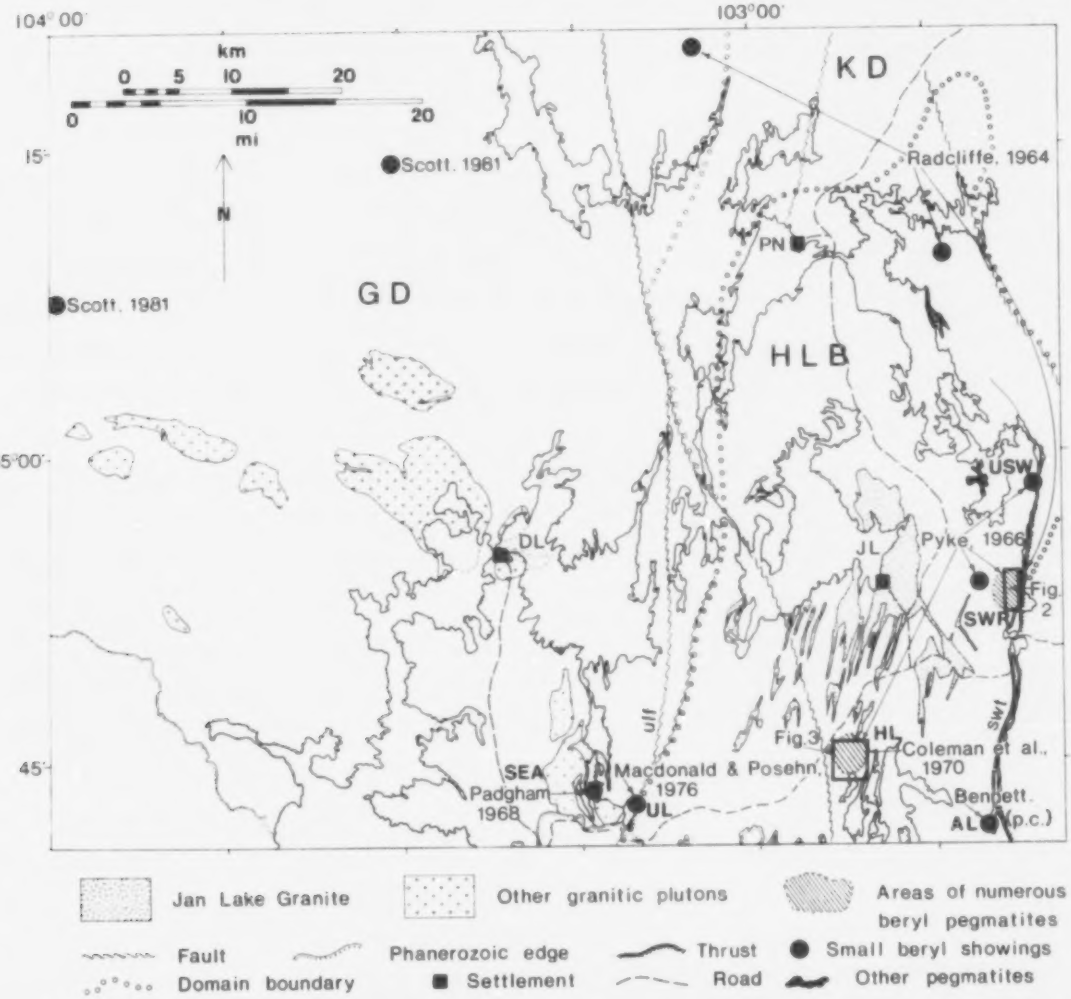

104° 00'
103°00'
15'
55°00'
45'
km
0 5 10 20
0 10 20
mi
N
KD
GD
HLB
Scott, 1981
Scott, 1981
Radcliffe, 1964
PN
USW
JL
Pyke, 1966
Fig. 2
SWR
DL
swt
ulf
Fig.3
HL
Coleman et al., 1970
SEA
Macdonald & Posehn, 1976
Padgham 1968
UL
Bennett (p.c.)
AL
Jan Lake Granite
Other granitic plutons
Areas of numerous beryl pegmatites
Fault
Phanerozoic edge
Thrust
Small beryl showings
Domain boundary
Settlement
Road
Other pegmatites

Figure 1 - Distribution of beryl occurrences in the Jan Lake area. Beryl occurrences: USW, Upper Sturgeon-weir River; SWR, Lower Sturgeon-weir River; HL, Hanson Lake; AL, Attree Lake; UL, Unser Lake; SEA, Southeast Arm. Domains: GD, Glennie Domain; HLB, Hanson Lake Block; KD, Kisseynew Domain. Faults: swt, Sturgeon-weir Thrust; ulf, Unser Lake Fault. Settlements: DL, Deschambault Lake; JL, Jan Lake; PN, Pelican Narrows. General geology modified from Macdonald (1981).

---

[1] Throughout the text the term 'pegmatite' is used to mean granite pegmatite.

No beryl has yet been recorded east of the Sturgeon-weir River thrust.

Pyke (1966) outlined four areas of beryliferous pegmatite all within the Hanson Lake Block; three just west of the Sturgeon-weir River and one northwest of Hanson Lake. He established that at Hanson Lake:

1) the pegmatites occupy the quartz diorite migmatite core of the overturned Jackpine Lake antiform;
2) beryl is more abundant than in the Sturgeon-weir River pegmatites (1-15 beryls/0.1 m^2 every 1 - 30 m compared to 1-12 beryls/0.1 m^2 every 200 m +) and
3) pegmatites are texturally and mineralogically zoned parallel to their contacts.

Mapping by Coleman *et al*. (1970) extended the area of known pegmatite mineralization at Hanson Lake south as far as Jackpine Lake and established that the dykes continued for great distances along strike. They identified manganotantalite as a minor accessory and defined two types of non-beryliferous pegmatite: 1) neosome with gradational contacts and cataclastic texture in the Kisseynew quartz diorites and 2) large post-folding bodies up to 70 m thick and 500 m long, distinguished by the presence of up to 5 percent biotite and a wide range of accessory minerals including hornblende, carbonate and chlorite.

Radcliffe (1964) conducted the only detailed study done to date on the beryliferous pegmatite dykes along the west bank of the Sturgeon-weir River near Birch Portage. He found that:

1) there is no apparent petrologic or major element geochemical difference between 'barren' and beryliferous pegmatites;
2) beryliferous pegmatites are nearly exclusively confined to the porphyroblastic hornblende-plagioclase gneiss (unit 3); whether because of geochemical-catalytic control, structural control (better fracturing, proximity to Sturgeon-weir River thrust) or topographic effect (fortuitous exposure of a beryliferous level because the rock unit forms higher ground), is not clear;
3) pegmatites likely formed by cotectic subsolvus crystallization of quartz, albite and potassic feldspar from fluids moving through tension fractures;
4) the beryl grew, not from *in situ* concentration of components by differentiation of static granitic magma, but from solutions moving through the pegmatite as it crystallized inwards from the sides; and
5) columbite-tantalite and monazite are rare accessories.

Previous work leaves many questions unanswered, for example:

- Is the beryl associated with any significant Li, Sn, F, Nb, Ta, W, or REE concentration, or any characteristic trace element signature that can be used to distinguish beryliferous from 'barren' pegmatites?
- Do beryl pegmatites from different areas have similar or different composition and is there any pattern to the variation (e.g. regional zoning)?
- Are the 'barren' pegmatites (i.e. those in which no beryl is visible) really devoid of beryllium mineralization or are the beryllium minerals just difficult to identify (e.g. quartz-like, massive, clear or white beryl; phenacite and chrysoberyl)?

In an attempt to answer these questions pegmatites were sampled for petrographic and geochemical analysis from three areas: Sturgeon-weir River, Hanson Lake and Unser Lake/Southeast Arm.

1. Petrographic Results

The important statistics and physical features of pegmatites from the three areas are listed in Table 1. Table 2 summarizes the main petrographic features

2. Sturgeon-weir River

The area comprises northerly-striking moderately east-dipping hornblende and biotite (Kisseynew) gneisses in the eastern limb of a northeast-plunging cylindrical antiform. They are intruded by northwesterly-striking, post-folding, synmetamorphic diabase dykes and later felsites. Beryliferous and 'barren' pegmatites occupy parallel but later extension fractures cross-cutting the foliation (Radcliffe, 1964; Pyke 1966). They locally branch or form *en echelon* groups and easterly-trending dykes typically terminate northerly-trending ones.

Symmetrical pegmatite zoning comprises a 1 cm bleached contact, 2-10 cm aplitic margin and coarse-grained quartz-rich core. Because of its uneven distribution, beryl is difficult to find even in dykes identified by Radcliffe as beryliferous; 'barren' pegmatites may contain beryl that just isn't visible at surface.

Unidentified accessory minerals include a 1 cm diameter hexagonal black glassy crystal (sample 0012) in 'barren' pegmatite surrounded by 2 cm wide zone of intense hematite alteration and radial cracks (sphene, columbite-tantalite or allanite?) and a tabular black mineral (sample 0187) in beryliferous pegmatite (xenotime, sphene, allanite or columbite-tantalite?). Autunite is present on some pegmatite fracture surfaces.

Host hornblende-plagioclase gneisses (unit 3) are altered at their contact with pegmatite. Modal analyses (Table 3) show that near the pegmatite contacts, potassic feldspar content is reduced from 10 percent to near zero and biotite increases from less than 1 percent to as much as 20 percent. Plagioclase becomes less calcic (from An39 to as low as An8). Biotite content is highest and plagioclase most sodic at the contact with 'barren' pegmatites.

No obvious differences in modal composition occur between 'barren' and beryliferous pegmatites from the same subareas (Table 4), confirming Radcliffe's previous observation, although there are clear differences

Table 1 – Pegmatite Statistics and Physical Features.

		AREA NAME	
PARAMETER	STURGEON-WEIR R.	HANSON LAKE	UNSER LAKE/SE ARM
Type of Pegmatite Body	Veins, sills and dykes	Dykes	Internal layers in composite granitic pluton; veins and dykes in country rock
Contacts	Sharp	Sharp	Hazy to sharp
Internal Zoning	Symmetrical; gradational	Asymmetrical; sharply defined	Concentric; sharp to gradational
Principal Strike Directions	N140-N165 (46%) N000-N015 (21%) N090-N100 (14%) N120-N130 (14%)	N010-N035 (72%) N035-N045 (11%) N100-N110 (5%) Other (12%)	N010-N038 (57%) N070 (29%) N135 (14%)
No.	28	82	7
Max Length	200 m	700 m	N/A
Dip Angles			
0-30 degrees	42%	5%	17%
30-60 degrees	40%	43%	0%
60-90 degrees	16%	52%	83%
	Maxima @ 0-10 deg (17%) 20-30 deg (19%)	Maxima @ 50-60 deg (22%) 80-90 deg (31%)	Maximum @ 80-90 deg (67%)
Dip Direction	Mainly W and SW	Exclusively E	Variable
No.	42	81	6
Estimated True Thickness	0-30 cm (72%) 30-70 cm (10%) 1-3 m (18%)	0-30 cm (40%) 30-70 cm (13%) 1-4 m (43%) 4-12 m (4%)	0-30 cm (60%) 30-70 cm (20%) 1 m (20%)
No.	63	101	5
Maximum Grain Sizes of Feldspar and Quartz	0-20 mm (42%)	0-20 mm (26%)	0-20 mm (43%)
	20-60 mm (50%)	30-50 mm (11%)	30-50 mm (7%)
		70-80 mm (3%)	70-80 mm (7%)
	100-150 cm (8%)	10-30 cm (54%)	10-30 cm (36%)
		50-60 cm (6%)	50-60 cm (7%)
No.	28	35	14
Xenoliths of Host Rock	Rare	A few present	Abundant at contacts;30-100cm
Beryl Diam	0-10 mm (92%) 10-20 mm (6%) 20-30 mm (2%)	0-10 mm (70%) 10-20 mm (22%) 20-50 mm (8%)	1 cm
No.	47	165	1
Beryl Length	0-5 mm (9%) 5-10 mm (36%) 15-20 mm (55%)	15-20 mm (7%) 25-40 mm (89%) 90-100 mm (4%)	2.5 cm
No.	11	44	1

No. = number of observations

in pegmatite composition between different subareas (Figure 2). Potassic feldspar content decreases from 44 percent (subarea A) to 12 percent (subarea B) in the order A-C-D-F-B; plagioclase increases from 31 percent (subarea A) to 55 percent (subarea B) in the order A-C = F-D-B and quartz content from 17 percent (subarea C) to 32 percent (subarea B) in the order C-D-A = F-B. Subareas B and F together form a north-northwest-trending strip of ground in which pegmatites are potassic feldspar-poor and quartz-rich, indicating a degree of regional compositional zoning.

3. Hanson Lake Pegmatites

Kisseynew-type quartz dioritic gneiss, migmatite and amphibolite agmatite occupy the core of the south-plunging Jackpine Lake Antiform which is cut by axial-planar beryliferous pegmatites and flanked by structurally and stratigraphically conformable Amisk-type mafic, intermediate and felsic volcanics (Coleman *et al.*, 1970). The volcanics were dated at 2521 ± 60 Ma and the beryliferous pegmatites at 1799 Ma by the Rb/Sr whole rock method (Coleman, 1970). Subsequent uranium-lead (zircon) ages suggest a much younger age of 1888 ± 12 Ma for the volcanics (Van Schmus *et al.*, 1987). Bickford *et al* (1988) report uranium-lead (zircon) ages of 1870 Ma and 1859 Ma for two samples of quartz diorites at Jackpine Lake.

As at Sturgeon-weir River, easterly striking dykes cut and displace northerly striking ones and locally, dykes branch or merge with each other. However, textural and compositional zoning is asymmetrical; a coarse-grained quartz-rich core is commonly separated from the western contact by a composite marginal zone up to 1 m or more thick comprising bands of aplite, granite and coarser (1-2 cm grain size) pegmatite, and from the eastern contact by a 10 cm or less zone of 5 mm grain size material. In the northwest where dykes are thickest and coarsest, pegmatite is more abundant than host rock.

Table 2 - Main Petrographic Features of the Pegmatites.

MINERAL	MODE OF OCCURRENCE AND CHARACTERISTICS		
	STURGEON WEIR RIVER	HANSON LAKE	UNSER LAKE/SOUTHEAST ARM
KSPAR	- large (4- 12 mm) pink, rarely blue grey or violet, anhedral to subhedral equant perthitic orthoclase grains containing euhedral inclusions of quartz, plagioclase, myrmekite, biotite and garnet - large rounded grains having pink granular recrystallized quartz-plagioclase margins; white, strained, broken and crushed cores and very fine grained quartz-plagioclase mosaic fracture-fillings - small (1 - 4 mm) interstitial grains of microcline - twice average model amount present in a 1 - 1.5 cm contact zone - coats joints in host rock - fills fractures in large plagioclase and beryl grains - occurs as irregular patches in cores of some plagioclase	- very large (20-60 cm) euhedral to subhedral, locally broken potassium feldspars graphically intergrown with quartz, or as blade-like concentrically zoned crystals perpendicular to the contact, disrupting the aplitic banding - large (up to 16 mm) subhedral rounded equant white-cored, pink- to red-margined grains of microperthitic untwinned orthoclase containing 1-2 mm inclusions of plagioclase, garnet and quartz and cracks filled with plagioclase. - small (1 - 2 mm) interstial micropcline grains - twice the average modal amount concentrated in a 3 cm contact zone	- large (up to 60 cm) euhedral graphic-textured brick red crystals - large (up to 12 mm) white-cored pink-margined, anhedral to subhedral equant strained, fractured and crushed perthitic (patch and ribbon) orthoclase grains containing euhedral inclusions of biotite, plagioclase and quartz and muscovite fracure-fillings - patches of orthoclase in the cores of some plagioclases - small (0.2 - 2 mm) interstitial or equant polygonal microcline grains in the groundmass mosaic
PLAGIOCLASE	- large (3 - 8 mm) anhedral rounded untwinned and multiply twinned grains; bent, cracked, crushed and reannealed to mosaic of equant grains with similar optical orientations; cracks filled with kspar, quartz, plagioclase and muscovite - small 0.5 - 1 mm twinned, equant polygonal or lath-shaped groundmass grains - variably altered to sericite; strong alterations responsible for greenish tinge	- 4mm contact zone of myrmekite-like quartz intergrowth - large (4 - 15 mm) rounded cracked, distorted, or crushed and recrystallized grains with fine-grained granular margins, fractures filled with potassic feldspar or quartz, and slightly sericitized cores - small (0.3 - 1 mm) equant polygonal or lath-shaped grains in a groundmass mosaic with quartz.	- small (0.3 - 3 mm) twinned and untwinned, slightly bent or strained, locally myrmekitic, variably sericitized grains - in zoned crystals core sericitization is more intense giving a green colour in hand specimen
QUARTZ	- large (3 - 4 mm), smokey clear or milky inequant grains; strained, crushed and recrystallized to interlocking mosaic of equant polygonal grains with sutured margins - small (0.4 - 0.8 mm) equant, polygonal and unstrained groundmass grains	- up to 1m patches of sheaved feathery, fibrous quartz-muscovite intergrowth - large (up to 12mm) moderately to severely strained smokey grey, milky or rarely citrine grains, locally crushed and recrystallized into an interlocking mosaic of sutured polygons - locally euhedral columnar grains perpendicular to contacts - small polygonal grains in groundmass mosaic with plagioclase.	- 2-30 cm patches of plumed, radiating sheaves of feathery, fibrous quartz-muscovite intergrowth form up to 30% of the rock in places - large (2 - 4 mm) smokey to black grains or milky to grey, strained crushed and annealed to mosaic of 0.2 - 1 mm interlocking equant sutured polygonal grains - small (0.2 - 0.8 mm) equant clear unstrained groundmass grains
MUSCOVITE	- large (up to 4 cm) books, some bent - more common as 2 - 6 mm books, some surrounded by 0.1 mm margin of plagioclase-Kspar-biotite, and as 0.2 - 0.6 mm ragged plates in groundmass - faint yellow pleochroism	- 1 - 4 cm diameter, up to 10 cm thick pale green books in the coarse-grained core zone - as 4 - 8 mm books closely associated with beryl and potassic feldspar or intergrown with quartz or locally concentrated in bands parallel to the zoning or at the contacts - very fine (0.01 - 1.5 mm) flakes scattered through the groundmass - locally encloses euhedral garnet. - faint yellow-green pleochroism.	- large (1 - 5 cm) euhedral pale green books - 0.2 - 2 mm ragged flakes or equant books commonly bent or showing slip twinning
BIOTITE	- green to dark green, brown to black 0.2 - 1.5 mm scattered flakes having abundant dark pleochroic haloes and in some cases altered to opaque and muscovite or chlorite - locally concentrated at pegamtite margins	- rare, deep green to yellow-brown scattered flakes or intergrown with muscovite	- large (3 - 6 cm) anhedral books - small (0.2 - 1 mm) brown, green, fox-red, and khaki groundmass flakes having abundant pleochroic haloes - in places intergrown with muscovite or altered to chlorite
BERYL	- creamy green, apple green, pale green, iron-stained, grey or colourless - mostly opaque, rarely transparent	- single crystals or clusters of 2 to 10 perpendicular to internal or external contacts or randomly oriented in the coarse-grained quartz-rich core - mostly euhedral combinations of hexagonal prism and basal pinacoid; some crystals are bent, some taper towards the contact from which they grew - mostly apple green; also golden brown, pale green, whitish green, white or bluish green; in rare cases have a green core and 1 mm white rim. - most commonly opaque, in rare cases translucent to transparent	- pale green opaque
GARNET	- 0.1 - 0.8 mm (up to 3 mm) red anhedral to euhedral fractured grains, occurring singly, in 1 - 2 cm clusters or in lines separating aplite from pegmatite - locally invaded by quartz or partially altered to chlorite, hematite, sericite or muscovite + opaque - rare biotite haloes	- Pinhead to 10 mm euhedral red, brownish red or rarely purple isolated grains, 1 - 50 mm diameter clusters and single lines along aplite contacts - locally in narrow zones around beryl crystals - larger grains distorted.	- large (3 - 10 mm) uncommon to rare, purple, pink and lilac euhedral transparent grains - 0.2 - 0.4 mm euhedral to subhedral grains enclosed in quartz - some altered to chlorite
MAGNETITE	- in 1 - 2 mm clusters; variably hematized	- locally abundant variably hematized 5 - 10 mm cubes	- absent
TOURMALINE	- absent	- absent	- up to 30 cm pods of 1 - 3 cm diameter, 4 cm long black crystals, some graphically intergrown with quartz

Table 3 – Country Rock Modal Analyses, Strugeon-weir River

RADCLIFFE UNIT No. MINERAL %	(1)	(1.1)	(3)	(3.1)	(3.2)	(3.3)	(4)	(4b)	(5)
KSPAR	2	40	10	<1	-	-	25	-	20
PLAGIOCLASE	56	25	48	58	48	40	35	7	65
COMPOSITION	An12	An9	An39*	An18	An36	An8	An27	An48	An46*
QUARTZ	30	-	27	27	29	40	25	3	10
MUSCOVITE	-	-	-	-	-	-	-	-	-
BIOTITE	10	-	<1	8	14	20	2	-	-
OPAQUE	-	-	-	tr	tr	-	<1	tr	-
APATITE	tr	-	tr	tr	<1	-	1	-	<1
EPIDOTE	-	-	-	-	-	-	-	20	tr
CHLORITE	-	-	-	-	-	-	-	-	2
HORNBLENDE	-	-	8	6	-	-	10	70	3
ACTINOLITE	2	10	-	-	9	-	-	-	-
DIOPSIDE	-	25	-	-	-	-	-	-	-
CARBONATE	-	-	-	-	tr	-	-	-	-
SPHENE	tr	-	<1	-	<1	-	2	-	-
ZIRCON	-	-	-	-	<1	-	-	-	-
No. OF THIN SECTIONS	1	1	2	8	2	1	1	1	1

UNITS DESCRIPTIONS AFTER RADCLIFFE, IN PYKE (1964)

(1) Porphyroblastic biotite gneiss
(1.1) Porphyroblastic calc-silicate gneiss: interbanded with (1)
(3) Porphyroblastic hornblende-plagioclase gneiss
    (3.1) & (3.2) varieties of (3) in contact beryl pegmatites
    (3.3) variety of (3) in contact with barren pegmatites
(4) Hornblende-potassium feldspar gneiss
(4b) Amphibolite lenses in hornblende-potassium feldspar gneiss
(5) Plagioclase-amphibole gneiss

* = composition of plagioclase not determined due to alteration; composition is the normative value calculated by Radcliffe (1964)

As at the Sturgeon-weir River area, host rocks in contact with pegmatite (Table 5) have higher, more albitic plagioclase content (53-54 percent compared to 32 percent; An8-12 compared to An59). Although pegmatites from two localities (0211 and 0234) show appreciably lower potassic feldspar and higher plagioclase contents (Table 4), compositions of pegmatites throughout the area are extremely uniform (see Figure 3 & Table 5). Smokey grey brown lozenge-shaped crystals of a quartz-like mineral occurring in some pegmatites were tentatively identified as the beryllium silicate phenacite.

4. Unser Lake/Southeast Arm

The area comprises rafted and injected migmatites, late-stage granites and mixed (mainly semipelitic) supracrustals of the Southeast Arm segment and Unser Lake Schist Belt, both components of the Glennie Domain. They are separated from the Hanson Lake Block to the east by the Unser Lake Fault, a branch of the Tabbernor Fault system (Macdonald & Posehn, 1976; Macdonald, 1981).

A composite pegmatite-granite intrusion occupying the area of Unser Lake has its contacts exposed along the lake shore. Within it, colour banded granite (10 cm scale bands), pegmatite and aplite occur as large irregular pods, sheets and dykes. Patches of plumed, radiating sheaves of feathery, fibrous quartz-muscovite intergrowth 2-30 cm across form up to 30 percent of the pegmatite in places. Several late-stage 10 cm wide, 1 - 2 m spaced, southeasterly-trending, near vertical, black, fine-grained quartz-tourmaline (dravite) dykes cut across the centre of the intrusion. Outside the contact and at Southeast Arm, dykes of pegmatite crosscut the country rock foliation.

Beryl mineralization in pegmatites is very sparse; only one crystal was located at Unser Lake and none of the beryls reported by Padgham (1968) at Southeast Arm were found. Turquoise, lath-shaped apatite crystals and pink-white-green particoloured tourmaline are rare accessories in the Unser Lake pegmatites. At the two localities, clots and pods of coarse (1 - 3 cm diameter, 4 cm long) black tourmaline up to 30 cm across, some graphically intergrown with quartz, occur in pegmatites. Both granite and pegmatite have two micas in equal amounts. In the Unser Lake intrusion, pegmatite is potassic feldspar-rich and plagioclase-poor (Table 6) whereas in granite, plagioclase predominates.

5. Regional Comparison of Pegmatite and Granite Compostions

Comparison of pegmatite petrography (Tables 2 and 4) and average modal analyses of pegmatites and granites from throughout the Jan Lake region (Table 7) show that:

1) All pegmatites show evidence of cataclasis and recrystallization;
2) Pegmatites from the three main areas (Sturgeon-weir River, Hanson Lake and Unser Lake/Southeast Arm) have significantly different compositions;
3) Upper Sturgeon-weir River pegmatites have a very different composition from the lower Sturgeon-weir River group;
4) Sturgeon-weir River beryliferous and 'barren' pegmatites are petrographically indistinguishable;

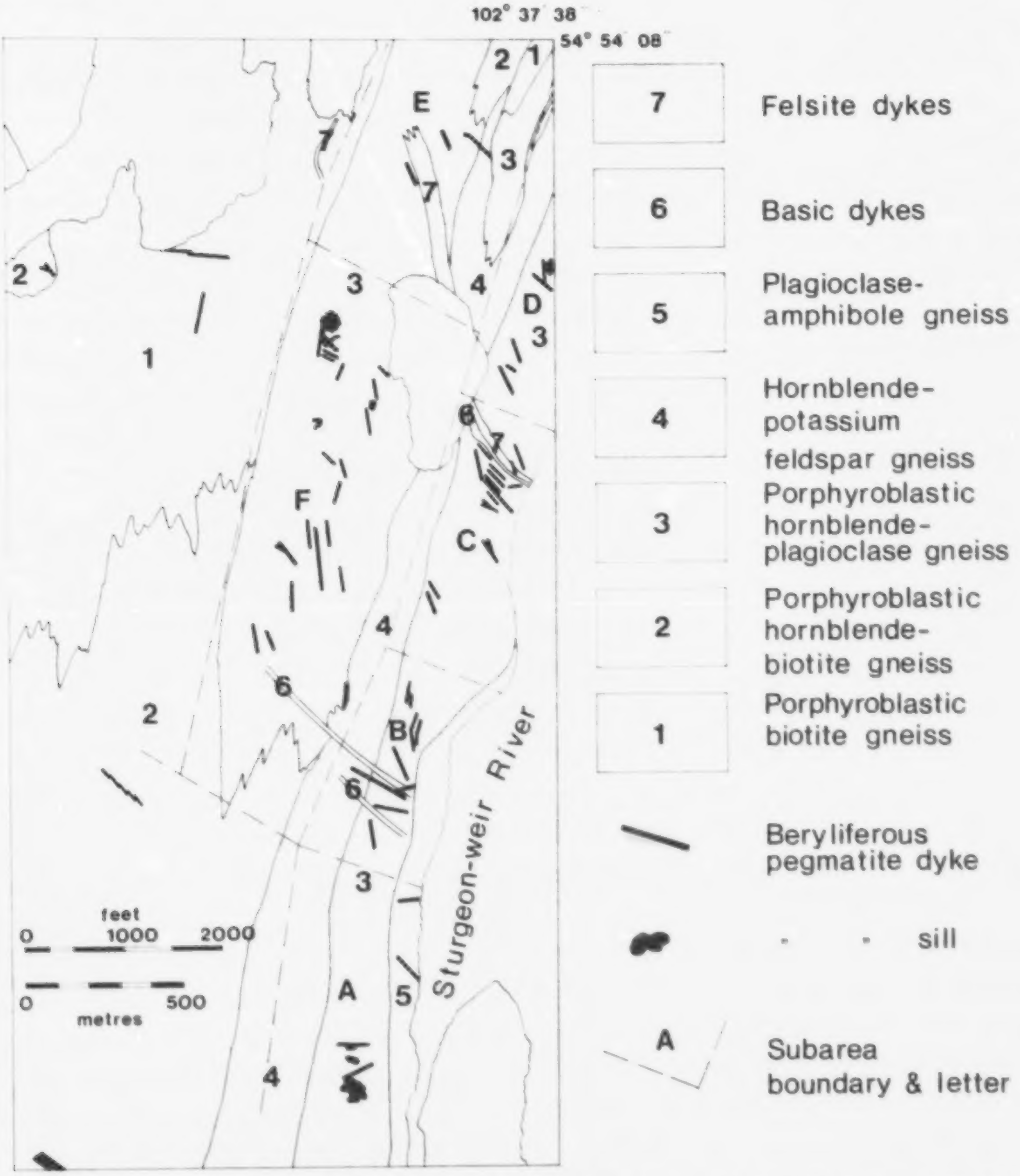

102° 37' 38"
54° 54' 08"
7 Felsite dykes
6 Basic dykes
5 Plagioclase-amphibole gneiss
4 Hornblende-potassium feldspar gneiss
3 Porphyroblastic hornblende-plagioclase gneiss
2 Porphyroblastic hornblende-biotite gneiss
1 Porphyroblastic biotite gneiss
Beryliferous pegmatite dyke
sill
A Subarea boundary & letter
feet
0 1000 2000
0 500
metres
Sturgeon-weir River
A
B
C
D
E
F

Figure 2 - Distribution of beryliferous pegmatites and sample subareas in the Sturgeon-weir River area. Geology modified from Radcliffe (1964); widths of all pegmatite dykes greatly exaggerated.

5) Rudimentary regional compositional zoning of pegmatites exists at Sturgeon-weir River but is not apparent elsewhere;
6) All the beryliferous pegmatites contain accessory garnet; the purple variety at Unser Lake probably differs in composition from those elsewhere;
7) The Unser Lake/Southeast Arm pegmatites and granites contain tourmaline and lack magnetite; Sturgeon-weir River and Hanson Lake pegmatites lack tourmaline and contain common magnetite;
8) Non-beryliferous pegmatites within the Jan Lake granite differ markedly from it in composition and
9) Beryliferous pegmatites distant from the Jan Lake granite have a close compositional affinity to it (including presence of accessory garnet and two micas) making it likely that the two are related (Macdonald & MacQuarrie 1978; Macdonald, 1981).

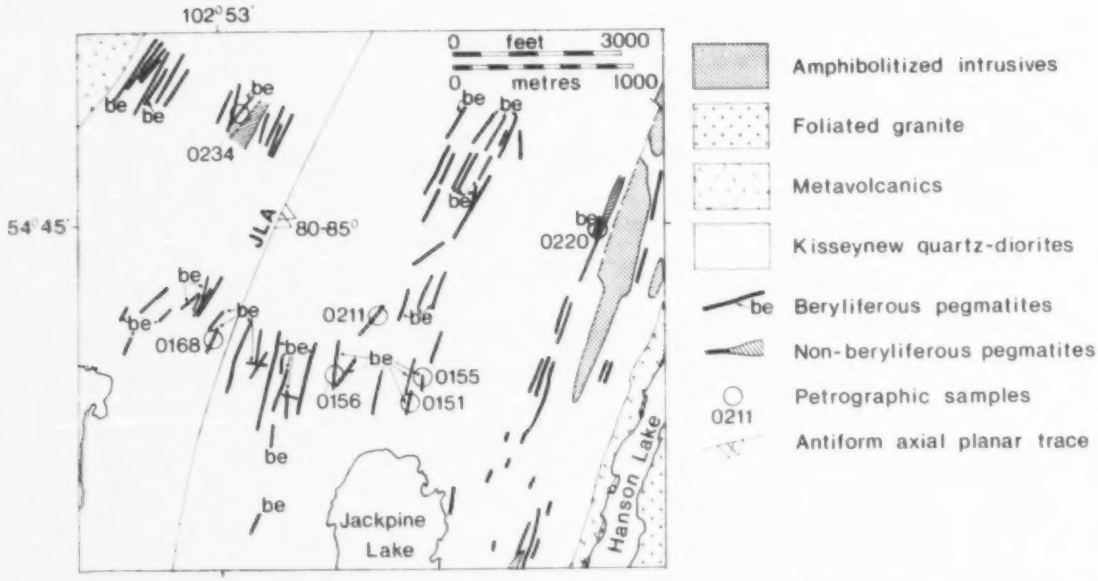

102°53'
54°45'
0 feet 3000
0 metres 1000
be
0234
JLA
80-85°
0220
0211
0168
0156
0155
0151
Jackpine Lake
Hanson Lake
Amphibolitized intrusives
Foliated granite
Metavolcanics
Kisseynew quartz-diorites
Beryliferous pegmatites
Non-beryliferous pegmatites
Petrographic samples
0211
Antiform axial planar trace

Figure 3 – Distribution of beryliferous pegmatites and petrographic samples in the Hanson Lake area. JLA = trace of the axial plane of the Jackpine Lake Antiform. Geology modified from Coleman et al. (1970). Width of pegmatites exaggerated.

6. Trace Element Geochemical Results

Chemical analyses for the Sturgeon-weir River and Hanson Lake pegmatites have been averaged for: 1) samples containing visible beryl, 2) samples containing no visible beryl (both taken from known beryliferous pegmatites) and 3) samples from 'barren' pegmatites (Table 8). Analyses of pegmatite accessory minerals are given in Table 9.

Significant beryllium values are present only in those pegmatites containing visible beryl; 'barren' pegmatites and those lacking visible beryl (some taken only a short distance from beryl mineralization) both have background values. This shows that traces of beryllium are not harboured by any of the common rock-forming silicates and that difficult to identify varieties of beryl or other beryllium minerals such as phenacite or chrysoberyl are not present. The sample tentatively identified as phenacite (0152 - Table 9) has too low a beryllium content for it to be a beryllium mineral.

Of the elements usually associated with beryllium, lithium is below the levels expected if lithium minerals (spodumene, lepidolite, petalite) were present; values at Sturgeon-weir River are abnormally low. Lithium in Hanson Lake muscovites is well below the maximum (3.5 percent) possible in lithium-rich environments; however, niobium, tin and cerium are anomalous in Hanson Lake 'barren' and beryliferous pegmatites. High tin in Hanson Lake garnets and muscovites indicates cassiterite may be present in the pegmatites, whereas significant tantalum occurs only in pegmatites containing visible beryl. The

Table 4 – Comparison of Beryliferous and Barren Pegmatites from Sturgeon-weir River Subareas.

SUBAREA	A	B		C		D	F	
TYPE MINERAL %	be	be	bar	be	bar	be	be	bar
KSPAR	44	12	10	39	53	25	22	20
PLAGIOCLASE	31	55	45	43	23	53	43	48
COMPOSITION	An10	An5	An8	An7	An4	An12	An9	An7
QUARTZ	24	32	40	17	24	22	32	32
MUSCOVITE	<1	-	tr	-	-	<1	2	-
BIOTITE	tr	-	-	tr	-	tr	<1	tr
OPAQUE	<1	tr	-	tr	-	tr	-	tr
GARNET	<1	1	5	tr	-	<1	<1	-
APATITE	tr	-	-	-	-	tr	-	-
BERYL	<1	-	-	<1	-	tr	tr	-
EPIDOTE	tr	-	-	-	-	-	-	-
No. OF THIN SECTIONS	4	1	1	5	1	4	5	2

be = beryliferous; bar = barren

low yttrium and abnormally low lanthanum values are similar in all pegmatites; yttrium in Hanson Lake garnets is well below the maximum (up to 2 percent) possible in rare earth rich environments. Cerium is highest in Hanson Lake pegmatites lacking visible beryl. The two unidentified black minerals from Sturgeon-weir River pegmatites are probably sphene (sample 0012) and allanite (sample 0187). Interestingly the Unser Lake pegmatites are low in all trace elements except lithium.

Table 5 – Modal Compositions of Hanson Lake Beryl Pegmatites and Contact Gneisses.

	BERYL PEGMATITES							CONTACT GNEISS		CTRY ROCK
SAMPLE No. MINERAL %	0151	0155	0156	0168	0211	0220	0234	*	**	0148
KSPAR	25	20	25	20	10	40	3	3	-	-
PLAGIOCLASE	50	40	53	40	60	40	62	54	53	32
COMPOSITION	An4	An5	An4	An8	An8	An4	An8	An8	An12	An59
QUARTZ	24	29	20	35	30	20	35	30	32	12
MUSCOVITE	tr	1	<1	3	-	tr	<1	-	-	-
BIOTITE	-	-	-	-	-	-	<1	5	15	5
OPAQUE	tr	-	-	1	-	-	-	tr	tr	1
GARNET	1	tr	1	1	tr	tr	-	tr	-	5
APATITE	-	tr	-	-	-	-	-	tr	tr	tr
BERYL	-	10	-	tr	-	-	-	-	-	-
EPIDOTE	-	-	-	-	-	-	tr	<1	tr	-
CHLORITE	-	-	-	-	-	-	-	tr	-	-
HORNBLENDE	-	-	-	-	-	-	-	7	-	45
SPHENE	-	-	-	-	-	-	-	tr	-	-
ALLANITE	-	-	-	-	-	-	-	tr	-	-

* Average of five samples; ** average of two samples

Table 6 – Modal Compositions of Unser Lake/Southeast Arm Granites, Pegmatites and Contact Gneisses.

	PEGMATITES			GRANITES			DYKE	COUNTRY ROCK	
SAMPLE No. MINERAL %	0133	0135	0138	0004	0139	0147	0140	0007	0003
KSPAR	25	50	70	25	25	25	-	-	5
PLAGIOCLASE	tr	15	12	30	36	40	-	1	7
COMPOSITION	An5	An10	An10	An20	An8	An8	-	An48	An30
QUARTZ	40	35	17	40	36	33	30	62	58
MUSCOVITE	35	1	1	2	3	1	-	1	10
BIOTITE	-	tr	-	3	tr	1	15	15	20
OPAQUE	-	-	-	-	-	-	-	1	-
GARNET	-	-	tr	-	-	-	-	-	-
APATITE	-	-	-	-	-	-	-	tr	tr
BERYL	-	-	-	-	-	-	-	-	-
TOURMALINE	-	-	-	-	-	-	55	-	-
ACTINOLITE	-	-	-	-	-	-	-	20	-
CHLORITE	-	-	tr	-	-	-	-	-	-

7. Discussion

Growth lines in potassic feldspar, tapering beryls and crystals pointing in from the contacts are all features indicative of growth from highly fluid solutions into open tension fractures. Repeated zoning and presence of beryl both in pegmatite cores and at zone contacts suggests growth from moving solutions that arrived in pulses of contrasting composition, rather than from static solutions that gradually differentiated *in situ.* In contrast, large euhedral potassic feldspars having graphic quartz intergrowth, and plumed fibrous quartz-muscovite intergrowth in the coarse-grained pegmatite core areas and the Unser Lake intrusion indicate growth from eutectic fluids that were probably static. If beryl growth required a constant supply of component elements only available from continually replenished fluids, the absence of beryl in these areas may be explained.

8. Economic Potential

Unser Lake/Southeast Arm pegmatites are practically devoid of beryl and Sturgeon-weir River pegmatites are too narrow and widely separated for them to have any economic potential. By contrast, Hanson Lake pegmatites, because of their abundance, large size, and higher more evenly distributed beryl content merit a more detailed assessment, including blasting of outcrops for fresher sample material. Some of the beryl in these pegmatites is translucent to transparent, suggesting the possibility of gem quality material.

9. References

Bickford, M. E., Collerson, K. D. and Lewry, J. F. (1988): U-Pb geochronology and isotopic studies of the Trans-Hudson Orogen in Saskatchewan; *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p112-116.

Coleman, L. C. (1970): Rb/Sr isochrons for some Precambrian rocks in the Hanson Lake area, Saskatchewan; Can. J. Earth Sci., v7, p338-345.

Table 7 - Comparison of Pegmatites and Granites from Different Areas.

GROUP/AREA	1	2	3	4	5	6	7	8
MINERAL %								
KSPAR	28	<1	26	20	48	25	34	tr
PLAGIOCLASE	45	67	41	49	9	35	34	48
COMPOSITION	An9	An6	An7	An6	An8	An12	An11	An30
QUARTZ	25	23	32	28	31	36	30	42
MUSCOVITE	<1	2	tr	1	12	2	1	<1
BIOTITE	tr	-	tr	tr	tr	2	1	5
OPAQUE	tr	tr	tr	tr	-	-	-	tr
GARNET	<1	7	1	<1	tr	-	tr	-
APATITE	tr	-	-	tr	-	-	tr	tr
BERYL	<1	-	-	1	-	-	-	-
EPIDOTE	tr	tr	-	tr	-	-	-	tr
CHLORITE	-	-	-	-	tr	-	-	5
No. OF THIN SECTIONS	19	3	5	7	3	3	2	2

AREAS: 1 - Sturgeon-weir River beryliferous pegmatites; 2 - Upper Sturgeon-weir River beryliferous pegmatites; 3 - Sturgeon-weir River barren pegmatites; 4 - Hanson Lake beryl pegmatites; 5 - Unser Lake/Southeast Arm pegmatites; 6 - Unser Lake/Southeast Arm granites; 7 - Jan Lake Granite; 8 - Pegmatites in Jan Lake Granite

Coleman, L. C., Gaskarth, J. W. and Smith, J. R. (1970): Geology and geochemistry of the Hanson Lake area, Saskatchewan; Sask. Res. Coun. Rep., 10, 156p.

Deer, W. A., Howie, R. A. and Zussman, J. (1962): Rock-forming Minerals; Volume 1 Ortho- and Ring Silicates; Longmans Publishers, 333p.

Hawkes, H. E. and Webb J. S. (1962): Geochemistry in Mineral Exploration; Harper and Row Publishers, 415p.

Johnson, R. L. (1967): The geology of the Hanson Lake area (east half), Saskatchewan; Sask. Dep. Miner. Resour., Rep. 117, 19p.

Macdonald, R. (1981): Compilation bedrock geology: Pelican Narrows and Amisk Lake areas; *in* Summary of Investigations 1981, Sask. Geol. Surv., Misc. Rep. 81-4, p16-23.

Macdonald, R. and Posehn, G. A. (1976): Re-investigation in the Pickerel River and Limestone-Tulabi Lake areas; *in* Summary of Investigations 1976, Sask. Geol. Surv., p44-52.

Macdonald, R. and MacQuarrie, R. R. (1978): Geological re-investigation mapping, Jan Lake area; *in* Summary of Investigations 1978, Sask. Geol. Surv., Misc. Rep. 78-10, p16-24.

Padgham, W. A. (1968): The geology of the Deschambault Lake district, Saskatchewan; Sask. Dep. Miner. Resour., Rep. 114, 92p.

Pyke, M. W. (1966): The geology of the Pelican Narrows and Birch Portage areas, Saskatchewan; Sask. Dep. Miner. Resour., Rep. 93, 68p.

Radcliffe, D. (1964): The geology of the Birch Portage beryl pegmatite deposit, Saskatchewan; unpublished M.Sc. Thesis, University of Alberta, 106p.

Scott, B. P. (1981): Geology of the Maynard Lake - Sandy Narrows (west) area; Sask. Miner. Resour., Rep. 186, 26p.

Van Schmus, W. R., Bickford, M. E., Lewry, J. F. and Macdonald, R. (1987): U-Pb geochronology in the Trans-Hudson Orogen, northern Saskatchewan, Canada; Can. J. Earth Sci., v24, p407-424.

Note on the personal communication from R. Bennett:

Johnson (1967, p18) states "No beryl was seen in the present area". However, Rick Bennett (Sask. Energy and Mines) informs me that the pegmatite on the west side of Attree Lake on the Sturgeon-weir River did contain one beryl crystal until Padgham's wife removed it.

Table 8 - Trace Element Content of Pegmatites.

SAMPLE AREA				ppm				
PEGMATITE TYPE	Be	Li	Nb	Ta	Sn	Ce	La	Y
STURGEON-WEIR								
be-pegmatites								
+ visible be								
Average (7)	478	4	24	15	<20	45	3	9
Range	17->2000	2-11	<1-61	<10-44	<20	32-83	<1-5	1-25
be-pegmatites								
+ no vis. be								
Average (6)	7	9	25	<10	22	43	4	17
Range	3-13	1-21	12-38	<10	<20-25	21-62	<1-7	3-46
'barren'								
pegmatites								
Average (4)	7	4	15	<10	<20	51	5	7
Range	5-10	1-4	<1-28	<10	<20	36-74	2-6	1-11
HANSON LAKE								
be-pegmatites								
+ visible be								
Average (5)	246	57	67	14	63	44	3	6
Range	6-444	20-193	38-142	<10-28	<20-222	33-70	2-5	2-13
be-pegmatites								
+ no vis. be								
Average (5)	4	47	21	<10	32	81	11	3
Range	<1-5	8-110	<1-58	<10	<20-59	48-184	2-43	<1-6
'barren'								
pegmatites								
Average (3)	4	80	54	<10	54	80	9	14
Range	<1-7	8-124	41-65	<10	<20-121	67-94	9	7-26
UNSER LAKE								
Average (3)	2	67	<1	<10	<20	51	3	2
	<1-4	31-89	<1	<10	<20	34-74	2-4	<1-3
Average felsic igneous rocks (Hawkes & Webb 1962, p359-374)	5.5	70	20	-	45	-	46	-

Extraction; HF-HNO3-HClO4-HCl. Analytical method; Induced Coupled Plasma - Atomic Emission Spectroscopy. Analyst; Bondar-Clegg & Co.

Table 9 - Trace Element5 Analyses of Mineral Separates

UNIDENTIFIED					ppm					
	Ba	Be	Ce	Cr	Ga	La	Nb	Pb	Y	Zn
Hanson Lake ?phenacite	18	78.8	100	709	26	20	17	<2	1	29
L. St-Weir 0012	1559	<0.5	>2000	1303	76	>5000	12	148	136	479
U. St-Weir 0187	37	148.3	>2000	503	>1000	>5000	391	1768	9704	197
Average*										
Sphene	134		8907			2530	792		4619	271
Allanite		786	78824			64576		1200	12442	351

* Derived from Deer et al.(1962) v1, p72-73 and p214-215

GARNETS				ppm				
	Be	Ce	Cr	Ga	La	Li	Sn	Y
Unser Lake 0005	<0.5	119	1591	74	<1	87	<20	142
Hanson Lake 0210	75.0	>2000	1521	330	459	164	239	309

MUSCOVITE		ppm	
	Rb	Li	Sn
Unser Lake			
0001	470	IS	38
0145	645	IS	51
Hanson Lake			
0214	6600	1042	855
0233	2500	IS	630

TOURMALINE	ppm	
	F	Li
Unser Lake/ SE Arm		
0129	1450	38
0142	2700	253

Extraction; HF-HNO3-HClO4-HCl (F by KOH). Analytical methods; Induced Coupled Plasma - Atomic Emission Spectroscopy (Li in mica and tourmaline by Atomic Absorption, Rb and Sn in mica by X-Ray Fluorescence, F in tourmaline by Specific Ion). Analyst; Bondar-Clegg & Co.

Field Observations on the Frontier, Box and Athona Granites, Goldfields Area, Saskatchewan

Edward C. Appleyard[1]

Appleyard, E.C. (1989): Field observations on the Frontier, Box and Athona Granites, Goldfields area, Saskatchewan: *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

The Goldfields area surrounding Lodge Bay on the north shore of Lake Athabasca contains the site of Saskatchewan's first significant gold mine (Jewitt and Gray, 1940). This deposit, the Box Mine, was staked by an Edmonton prospector, Tom Box, in July, 1934, and after an unhurried period of exploration and development the Consolidated Mining and Smelting Company of Canada Ltd. brought the deposit into production in June, 1939. Operations continued until shut down in 1942 due to World War II labour shortages.

Approximately two kilometres to the east, the Athona Mine was explored by underground development during 1937 and 1938 (Jiricka, 1984) but operations ceased in 1939 prior to production being achieved. Amongst numerous other gold showings discovered during this same era, the Frontier occurrence, approximately 875 metres north-west of the Box Mine, was trenched, drilled and explored by about 300 m of underground development during 1935 to 1937. The option to this property was also dropped in 1939 (Jiricka, 1984).

During the 1950's and 1960's the area was again intensively prospected, this time primarily for uranium in conjunction with the activity associated with the Beaverlodge discoveries. The area was "rediscovered" for its gold potential in the early 1980's, the most recent work being that of Saskatchewan Mining Development Corporation in the Frontier and adjacent areas in 1981 to 1983 and RJK Mineral Corp. on the former Box and Athona properties during 1988 and 1989.

1. Regional and Local Geological Setting

The Goldfields area falls within the recently defined Nevins Lake Block (Macdonald, 1983). Lying within the Western Craton of Lewry and Sibbald (1977) the Nevins Lake Block is part of the western foreland to the Trans-Hudson Orogen to the southeast. The Nevins Lake Block comprises a basement complex yielding Archean ages, 3020 - 3014 Ma (Van Schmus *et al.*, 1986), and an overlying miogeosynclinal supracrustal assemblage, the Murmac Bay Group, of probable early Lower Proterozoic age (Siderian period; Cowie *et al.*, 1989). In the Goldfields - Nicholson Bay area, the Murmac Bay Group is intruded by a suite of small granitoid bodies referred to collectively as the "North Shore Plutons" with U-Pb and Rb-Sr ages ranging from ca. 2350 to 2000 Ma (Macdonald, 1987). Around Lodge Bay, the North Shore plutonic suite includes the three "granites" that form the focus of this study, i.e. the Frontier, Box and Athona granites. These bodies are also referred to locally as the "mine granites" (Sibbald and Jiricka, 1986). All are auriferous and each hosts a significant gold prospect. They are also pyritic, typically brick-red in colour and host two distinct ages of quartz veins. The older are massive quartz and carry the bulk of the gold mineralization, whereas the younger are characterized by euhedral quartz accompanied by pitchblende and hematite.

2. Objectives of the Study

Ever since the discovery of these occurrences there has been a conspicuous lack of concensus on the genesis of these granites and their constituent gold mineralization. The different genetic models have bred a parallel spectrum of ore control models. The present study has therefore been designed to evaluate the genetic history of each of the rock sequences that host these occurrences and their gold-bearing quartz veins. The approach to be used is based on field, petrographic and lithogeochemical observations and data, with mass balance assessments of metasomatic phenomena whenever appropriate, and is designed to complement recent structural, fluid inclusion and isotopic studies of the deposits (Quirt and Rees, 1987; Roberts and Tyedmers, 1988 and work in progress by M. Rees at the University of Saskatchewan).

3. Genetic Models for the "Mine Granites"

An early, conventional model for the origin of the Box deposit was offered by Jewitt and Gray (1940) in which they described the emplacement events as involving initial intrusion and solidification of the granite, deformation of the intrusive body producing foliated margins and a stockwork-like fracture network, the intrusion of the granite by several amphibolite lenses and, finally, the filling of the fractures by gold-pyrite-quartz veins.

Writing about the same time, Swanson (1938; quoted by Mason, 1989) introduced the ideas that the Box "granite" comprises "granitized or otherwise metamorphosed sediments and sheared basic intrusions" and that the gold was initially controlled by stratigraphic factors but was later redistributed into fold-related structures.

---

[1] Department of Earth Sciences, University of Waterloo, Waterloo, Ontario

Beck (1969) associated the Box and Athona granites with what he termed "Y2-type granites" and briefly referred to these as representing various stages of a composite phase of intrusion or replacement.

On the basis of extensive exploratory mapping and drilling, Jiricka concluded (1984, p.21) that the "so-called 'Frontier granite'....is actually a band of arkosic quartzite" although certain stratabound units within the metasediments were identified as being marked by intense quartz veining, silicification, feldspathization, hematization, chloritization and pyritization. His genetic model (p.49-51) proposed that hydrothermal solutions derived from a granite pluton at depth had been channelled along axial planar "fault/fracture systems", ponded beneath amphibolite sills and eventually dissipated laterally along highly fractured horizons of brittle arkosic quartzite where they resulted in extensive granitization phenomena.

Sibbald and Jiricka (1986) briefly sketched a similar but less specific origin, drawing attention to the common occurrence of transitional contacts, not only with the country rocks but also between different phases of granite, They also pointed to the apparent association of albite and gold, but concluded that there was "no dependency of the two phenomena". In particular the validity of any model that requires the transformation of sediments to granite by isochemical processes is questioned.

Quirt and Rees (1987) briefly reported on a study in progress on the Frontier occurrence which focussed on elucidating the nature of the assumed granitization process. They proposed a small volume loss accompanied the alteration, making possible the introduction of significant amounts of SiO_2; their calculations showed that no potash introduction was necessary under these constraints but that losses of substantial amounts of many other elements were required. Quirt (1988) reported that the study was continuing.

Appleyard (1988) independently conducted a metasomatic assessment on Frontier lithogeochemical data in which a suite of nine high field strength and transition elements was identified as having been largely immobile during the assumed granitization episode. This constraint pointed to a process that required substantial introduction of Si, Al, K, Na, Ca, Ba, Rb, Sr, Cu and especially Au and S. Very limited losses were indicated. This process requires volume increases during granitization of ca. 50 percent for "transitional" feldspathized arkosic quartzites and ca. 150 percent for the massive granite samples. The mechanism proposed for this process is infiltration of a highly fluid magma, possibly similar to a pegmatitic fluid, with a source in a granite body at depth.

Finally, Mason (1989) preferred an essentially isochemical anatectic model, at least for the Box granite and possibly for the Athona. Specifically, he proposed (p.31) "that the Box Mine 'granite' originated during the initial high grade metamorphism by partial melting of an arkosic lens of composition approaching that of the Bowen and Tuttle residual system". Furthermore, he extended the model to the country rock gneisses which are extensively migmatitic with thin folia, lenses or layers of granitic material that frequently resemble the Box 'granite'.

As this summary indicates, there has been substantially more speculation than agreement on the genesis of the three 'mine granites'. The present study is intended to further test Appleyard's "magmatic infiltration" model which appears to be conceptually closest to Jiricka's "ponded hydrothermal fluids" model.

4. Pertinent Field Observations

All three occurrences were examined in the field during July, 1989. Collections of samples were obtained both of surface rocks and, in the case of the Box and Athona occurrences, of drill core. A brief summary of the observations that are most pertinent to the genetic question follows.

a) Frontier Occurrence

On the basis of mapping by Saskatchewan Mining Development Corporation (Jiricka, 1984), the mineralized zones at the Frontier occurrence are conformable with the strike of quartzites and arkoses, are approximately 600 m in length, with an outcrop width of 25 to 65 m, and involve several different stratigraphic horizons. The host rocks were identified by SMDC, as being a metasedimentary sequence of: 1) white, locally pebble-bearing quartzite, 2) ferruginous, hematitic, in some places brecciated quartzite, 3) dolomitic (calc-silicate-bearing) quartzite, 4) argillaceous quartzite grading towards muscovite-chlorite schist, and 5) arkosic, potassium feldspar-rich quartzite.

Alteration or replacement phenomena that were evident in the field include silicification (including quartz veining), feldspathization, hematization, chloritization and pyritization. The observations that indicate that these are secondary (metasomatic) phenomena are varied and include the following:

1). Bedding and layering structures in the sediments become blurred or massive in appearance, commonly in association with a reddening of the rock colour and an apparent increase in feldspar;
2). Areas of reddish, relatively massive "transitional" rock possess fine chloritic streaks or schlieren which project a "ghost" bedding parallel to the layering in adjacent quartzites;
3). Massive, reddish, feldspathic units contain sparse, finely disseminated pyrite not apparent in the unaltered units;
4). Foliated facies of the metasediments may contain vivid, brick-red, saccharoidal-textured feldspathic or quartzo-feldspathic streaks following foliation planes in rocks that are otherwise brownish or greenish;
5). Quartzites that are characterized principally by phyllosilicate accessory minerals, muscovite and chlorite,

become feldspathic with a concomitant change in texture from schistose to granulitic; and

6.) Flooding of initially whitish, yellowish or greenish quartzites by patches and spots of reddish colouration appear to mark areas of introduction of feldspar.

Massive granite with an "igneous" aspect is a very sparse constituent in the exposures examined. Typically the "granite" component consists of veinlets cm in thickness (most commonly 1-2 cm thick) emplaced quasi-conformably within the metasediment foliation. In hand specimen these "granite" veinlets wedge apart the foliation in a dilatant manner. Feldspathization and other replacement alterations normally permeate the host-rock adjacent to the veins. The amount of "granite" present in the trenches, pits and outcrops examined ranged from < 10 percent to minimal amounts. It is probable that there is < 1 percent massive, igneous-appearing "granite" within the whole Frontier section.

Jiricka (1984) reports that gold mineralization is controlled both by stratigraphic properties and by cross-structures that he attributes to later regional folding.

b) Box Occurrence

Mason (1989) defined the Box granite as being the essentially unfoliated product of the anatectic metamorphism of an assumed arkosic protolith. This definition, which deliberately excludes any foliated facies, appears to be a satisfactory working definition of the granite for the exploration geologists on site inasmuch as it includes all that portion of the body that appears to have ore potential while it excludes the apparently barren sections. However, it is not a satisfactory definition from a genetic viewpoint.

The Box granite consists of a linked pair of thin lensoid sheets of typically medium-coarse-grained, brick-red granite, 775 m in length averaging ca. 40 m in outcrop width. It strikes east-northeast and on average dips 42° to the southeast parallel to the regional strike and dip of the sedimentary host sequence. It thins out toward each end and may terminate in a splay of migmatitic veins. As noted by Mason (1989) there are no chilled margins and no contact hornfelsing of the host rocks but these characteristics would not necessarily be expected in a syn-orogenic body. Explicit cross-cutting relationships with the country rocks also appear to be lacking, but rare, slab-like xenoliths of country schists and quartzite and several screens of foliated, feldspathized schist, up to several metres in thickness represent inclusions of the host rocks within the granite body. Similarly, four small, schistose amphibolite lenses which resemble those in the country rocks occur within the "mine granite".

Because outcrop is poor at each of the distal ends of the body the emplacement geometry of the body is difficult to determine. Where, however, the southern of the two lenses terminates in a southwesterly direction, it appears that the foliations of the host sediments diverge around both sides of the tapered end of the granite. Marginal facies of the granite are marked by a distinct foliation made up of thin lenticles of chlorite and muscovite. Towards the core of the body these tend to become less abundant and more disrupted by porphyroblastic quartz and feldspar while towards the country rock they merge into chloritic streaks and layers with the granitic fraction tending to become restricted to arteritic veinlets. Depending on the lithology of the host rock the transition from massive granite through foliated granite to migmatitic country rocks may occur over widths from a few cm to 5 m. Migmatitic country rocks in which the arteritic fraction is brick-red, medium-coarse grained and may possess abundant quartz ladder veinlets, extend for distances exceeding 70 m from the granite margin. This generation of migmatites appears to be co-genetic with the Box granite. If so, genetically, the granite must include the foliated portions of the main body as well as the migmatitic fraction in the flanking sequences.

The granite is in contact with quartzite, quartz-rich chlorite-muscovite schists, amphibolite and quartzo-feldspathic gneisses at various points along its principal contacts. Marginal zones of the granite may be yellowish or greenish rather than red and be notably enriched in chlorite as schlieren and folia and as fracture surface coatings; these phenomena seem to be most marked where the granite is in contact with amphibolite or chlorite-rich country rocks.

Massive facies of the granite, although initially brick-red in colour from its most abundant constituent feldspar, may be further stained red, especially along fractures and joints by ferric oxides etc., apparently resulting from the weathering of sparse disseminated pyrite. The foliated marginal and internal zones show this characteristic to a lesser degree as do the host rock zones with Box-type granite veinlets.

c) Athona Occurrence

The Athona granite is emplaced against a footwall complex of chlorite-, muscovite- and biotite-, amphibole- and rarely clinopyroxene-bearing quartzo-feldspathic gneisses similar in general lithological type to the country rocks hosting the Box granite. No hangingwall sequence is preserved. The northern contact with footwall gneisses appears to be conformable but is poorly exposed. This boundary strikes approximately east-west and dips gently (ca. 15° to 20°) to the south. A major upright, open syncline, termed the Goldfields Syncline by Sibbald (1984), comprises the local structure; the Athona rocks occupy the core of this fold.

The Athona 'mine' granite is similar to the Frontier and Box granites in being typically brick-red in colour, sparsely pyritic, medium-coarse grained, quartz-rich and possessing relatively abundant auriferous quartz veins. It differs in being more internally variable in both colour and mineralogy, in having feldspar-rich and feldspar-poor facies in addition to quartz-rich and quartz-poor facies. Grey, white, yellowish, flesh- and salmon-coloured facies, along with the more typical brick-red coloured granite, occur throughout the peninsula with no discernible pattern. Mason (1989) reports that the granite (*sensu lato*) includes facies of granodiorite, diorite, monzodiorite, monzonite, and quartz syenite as well as granite (*sensu stricto*).

A major amphibolite unit forms three enclaves within the Athona granite outcrop area. Contacts between the amphibolite and granite are invariably sheared but the granite is younger than the mafic rocks. Roberts and Tyedmers (1988) summarized the structural evidence for these age relations. In addition, thin veinlets of granite were observed cutting amphibolite and enclosing xenoliths of the mafic rock. A zone of reddish feldspars adjacent to granitic veinlets in amphibolite appear to be a feldspathization phenomenon; Mason (1989) reports the feldspar to be hematite-dusted plagioclase in similar examples.

Contacts between Athona granite and host metasedimentary gneisses are best observed in shore line exposures on the eastern and southwestern coasts of the Athona peninsula and in association with a large "enclave" of quartzite between the "Pond" and the eastern shore (for location see map accompanying Roberts and Tyedmers, 1988). In all but the latter locality the contacts are sheared.

The contact at the southwest side of the peninsula has mildly foliated granite in sheared contact with intensely foliated quartzofeldspathic gneisses. The granite is bleached from its usual brick-red to a yellowish-salmon colour for 2 to 3 m from the gneisses. At several locations within 20 m of the contact the granite contains discrete, well-defined angular xenoliths of grey, quartzofeldspathic gneiss. Also present are much more vaguely defined schlieren of mafic minerals that appear to represent intensively assimilated wall-rock inclusions. Reddish feldspar porphyroblasts are present not only within the schlieren and xenoliths but also growing across their margins into the surrounding granite.

Nearby the granite contains patches of much coarser grained, pegmatoid character. These comprise small, irregular, vaguely bounded areas, which clearly formed *in situ*. The normal granite, pegmatoid patches and xenoliths are all cut by thin (2 to 3 cm) veinlets of fine-grained, aplitic granite.

Along the east side of the peninsula, between the coast and the "Pond", occurs an area comprising at least 3500 m^2 of quartzite and quartz-rich metasediments. Some of the quartzites are strongly hematized and resemble those in the Frontier area. Although the transition from quartzite to granite is well exposed to both the north and south, no discrete contact could be observed. The transition is marked by a gradual increase in the amount of feldspar, a coarsening of the texture and the loss of planar fabrics.

A drill-hole which cut *ca*. 40 m of granite and then *ca*. 60 m of the footwall gneisses along the northern contact provides another view of the relationship between the granite and its host rocks. The granite acquires a strong foliation 6.5 m from the gneiss contact. Within this distance the foliation is considerably disrupted and cut by numerous chlorite-rich veins and chlorite-coated shear surfaces. The gneisses are irregularly feldspathized throughout the entire 60 m section of core. The style of alteration differs from that associated with the Box granite in that it is marked by strong feldspar porphyroblastesis rather than arteritic migmatization. Where the feldspathization is intense the foliation of the gneisses becomes obscure, the rock gradually acquires a massive character and takes on an aspect very similar to some fine-grained facies of the Athona granite.

5. Conclusions

The controversy associated with the origin of these three granites would appear very familiar to the petrologists of the 1930's to the 1950's when the "granite problem" was one of the hottest topics around. Since then, we have tended to lose sight of many of the arguments, observations and ideas that were current then. The fact that many granites exhibit confusing signs of both magmatic and metasomatic genetic processes was very well recognized in those days and gave rise to two "camps" who vigorously contested one another, the magmatists or "pontiffs" and the migmatists or "soaks" (Read, 1957). Gradually, petrologists came to accept that the truth lies in an amalgamation of the two models or, as in Read's famous phrase, "There are granites and granites....and all of them may likely be of one connected origin" (Read, 1957, p.193).

The observations reviewed in the above account indicate that a low viscosity, injected magma must have been present at all three localities, but equally clearly, it must have been accompanied by diffuse fluids capable of permeating the host rocks and enclaves and, according to the context, altering them in ways that are crudely described under the terms of granitization, feldspathization, silicification, pyritization, etc.

The model I proposed a year ago (Appleyard, 1988) now seems to me to be not only tenable but preferred. On the question of the source of the magma, I observed nothing that convinced me of local anatexis in any of the three occurrences. Rather the similarities in the three granites indicates to me that a common source at depth is probable with their differences being functions of the level at which they are now exposed and how they interacted with their local host rocks. The continuation of this study will be focused to further test this hypothesis.

6. References

Appleyard, E.C. (1988): The origin of the Frontier granite, Goldfields area, Saskatchewan: a metasomatic assessment; *In* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p161-167.

Beck, L.S. (1969): Uranium deposits of the Athabasca region; Sask. Dep. Miner. Resour., Rep. 126, 139p.

Cowie, J.W., Ziegler, W. and Remane, J. (1989): Stratigraphic Commission accelerates progress, 1984 to 1989; Episodes, v12, p79-83.

Jewitt, W.G. and Gray, S. (1940): The Box mine of the Consolidated Mining and Smelting Company of Canada, Limited; Trans. Can. Inst. Min. Metall., v43, p447-467.

Jiricka, D.E. (1984): Saskatchewan Mining Development Corporation, Exploration 1983, Lodge Bay Project, CBS 5664, 5665 and 5677, S-98948, Athabasca Mining District, Saskatchewan, NTS-74-N-07, -08; Sask. Energy Mines, Assessment Rep. 74N-07-0315, 59p.

Lewry, J.F. and Sibbald, T.I.I. (1977): Variation in lithology and tectonometamorphic relationships in the Precambrian basement of northern Saskatchewan; Can. J. Earth Sci., v14, p1453-1467.

Macdonald, R. (1983): Geology and regional context of the Oldman Lake area; *in* Summary of Investigations 1983; Sask. Geol. Surv., Misc. Rep. 83-4, p19-23.

___________ (1987): Update on the Precambrian geology and domainal classification of northern Saskatchewan; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p87-104.

Mason, I.M. (1989): Goldfields Project, geology and drilling; Private internal report prepared for R.J.K. Mineral Corp., 58p.

Quirt, D. (1988): Current mineral deposit research at the Saskatchewan Research Council; *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p179-180.

Quirt, D. and Rees, M. (1987): Current research in mineral deposits at the Saskatchewan Research Council; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p160-163.

Read, H.H. (1957): The Granite Controversy; Thomas Murby & Co., London, 430p.

Roberts, R.G. and Tyedmers, P.H. (1988): Structural controls of the Box and Athona deposits, Goldfields, Saskatchewan: Progress Report; *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p82-83.

Sibbald, T.I.I. (1984): Gold metallogenic studies: Goldfields area; *in* Summary of Investigations 1984, Sask. Geol. Surv., Misc. Rep. 84-4, p116-121.

Sibbald, T.I.I. and Jiricka, D.E. (1986): Geology of the gold deposits, Goldfields, Saskatchewan; *in* Clark, L.A. (ed.), Gold in the Western Shield; Can. Inst. Min. Metall., Spec. Vol. 38, p412-414.

Van Schmus, W.R., Parsons, S.S., Macdonald, R. and Sibbald, T.I.I. (1986): Preliminary results from U-Pb zircon geochronology of the Uranium City region, northwest Saskatchewan; *in* Summary of Investigations 1986, Sask. Geol. Surv., Misc. Rep. 86-4, p108-111.

The Wollaston Group and Its Underlying Archean Basement in Saskatchewan: 1989 Fieldwork and Preliminary Observations

Irvine R. Annesley[1] *and Catherine Madore*[2]

Annesley, I.R. and Madore, C. (1989): The Wollaston Group and its underlying Archean basement in Saskatchewan: 1989 fieldwork and preliminary observations *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

A detailed investigation of the geological characteristics of the Wollaston Group and the underlying Archean basement with respect to uranium mineralization was initiated last year under a joint venture agreement between Saskatchewan Energy and Mines and Saskatchewan Research Council. This work was reported in the 1988 Summary of Investigations (Annesley and Madore, 1988) and elsewhere (Annesley, 1989a and 1989b; Annesley and Madore, 1989). The results and recommendations of this preliminary investigation indicated that further work was necessary. As a consequence, a new joint venture agreement between Cameco, CEGB Exploration (Canada) Ltd., Cominco Ltd., Interuranium Canada Ltd., PNC Exploration (Canada) Co. Ltd, Uranerz Exploration and Mining Ltd., Saskatchewan Energy and Mines, and Saskatchewan Research Council was negotiated. The major purpose of this project is to refine the field, petrographic, geochemical, and stratigraphic attributes of the various rock units of the Wollaston Group after "looking through" the Hudsonian structural-metamorphic overprint. A secondary aspect of the project is to determine the role of lithostratigraphy, structure, and metamorphism in the metallogenesis of unconformity-type uranium deposits. The ultimate goal is to add to or modify present metallogenic models of this deposit type, and hence improve the exploration strategy.

This report describes the progress of this summer's work. Some of the preliminary observations and interpretations, which are reported here, may change or be modified by further research. The final SRC report of this project, including the results and interpretation of all work and analyses, will be completed in April of 1991, and released after a two year period of confidentiality.

1. 1989 Field Work

The field work in 1989 was carried out by a two-person field party during the months of June, July, and August. The large study area is approximately trapezoid in shape (Figure 1). Its western boundary is defined by the Key Lake road from km 80 to kilometre 220, and the eastern boundary by a line trending northwards, parallel to and east of the Rabbit Lake road, from Kilometre 160 to Hatchet Lake. The northwestern boundary extends from Kilometre 220 of the Key Lake road northeastwards to Hatchet Lake, and the southeastern boundary from Kilometre 80 of the Key Lake road northeastwards to Kilometre 160 of the Rabbit Lake road.

Sub-areas and drill holes of importance to be mapped, core logged, and/or sampled were identified from compilation, previous studies in the region, and from recommendations of K. Kogler (Uranerz Exploration and Mining Ltd.), V. Sopuck (Cameco), H. Quarch (Interuranium Canada Ltd.), and T.I.I. Sibbald (Saskatchewan Energy and Mines). Ten different sites (see Figure 1 for location) were visited during the summer, including:

1) Kapesin Lake - Zimmer Lake (outcrop and drill core),
2) MacArthur River (drill core),
3) Key Lake road (outcrop),
4) Karin Lake (outcrop and drill core),
5) Bullseye Lake (drill core),
6) Nekweaga Bay - Morell Lake (outcrop),
7) Cigar Lake - Tibia Lake (drill core),
8) Robertson Lake (drill core),
9) Rabbit Lake - Collins Bay (drill core and outcrop) and
10) Dragon Lake - Raven Lake - Horseshoe Lake (outcrop and drill core).

Outcrops and drill core sites were visited via foot, road, air, and water. Approximately 130 outcrop samples and 460 drill core samples were collected. Thirty drill holes were core logged and sampled for construction of stratigraphic sections and another 39 drill holes were examined and sampled for purposes of stratigraphic correlation.

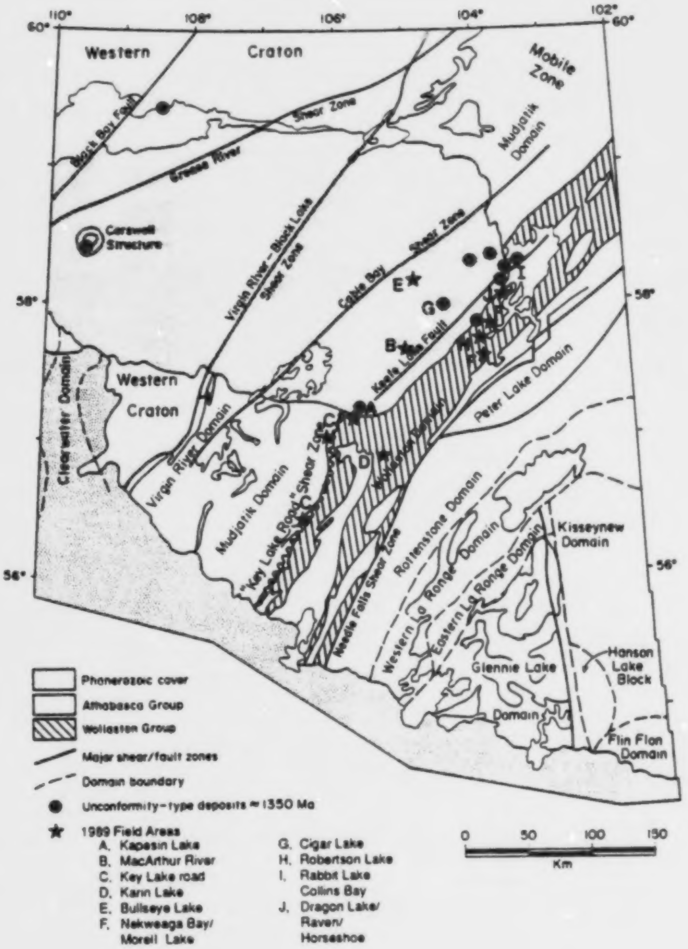
2. General Geology

The study area lies within the Wollaston Domain and the eastern part of the Mudjatik Domain, two of the major subdivisions of the Cree Lake Zone of the Trans-Hudson Orogen (Lewry *et al.*, 1985).

The Wollaston Domain is a northeast-trending belt, which typically comprises folded metasediments overlying antiformal Archean granitoid gneisses. The metasedimentary rocks are assigned an Aphebian age

---

(1) Minerals/Groundwater Program, Resources Technology Division, Saskatchewan Research Council, Saskatoon
(2) Department of Geology, University of Ottawa, Ottawa, Ontario



110°
108°
106°
104°
102°
60°
58°
56°
Western Craton
Mobile Zone
Black Bay Fault
Grease River Shear Zone
Carswell Structure
Virgin River – Black Lake Shear Zone
Cable Bay Shear Zone
Mudjatik Domain
Western Craton
Clearwater Domain
Virgin River Domain
Mudjatik Domain
"Key Lake Road" Shear Zone
Wollaston Domain
Needle Falls Shear Zone
Rottenstone Domain
Western La Ronge Domain
Eastern La Ronge Domain
Peter Lake Domain
Kisseynew Domain
Glennie Lake Domain
Hanson Lake Block
Flin Flon Domain
Knife Lake Fault
A
B
C
D
E
F
G
H
I
J
Phanerozoic cover
Athabasca Group
Wollaston Group
Major shear/fault zones
Domain boundary
Unconformity-type deposits ≈ 1350 Ma
1989 Field Areas
A. Kapesin Lake
B. MacArthur River
C. Key Lake road
D. Karin Lake
E. Bullseye Lake
F. Nekweaga Bay/ Morell Lake
G. Cigar Lake
H. Robertson Lake
I. Rabbit Lake Collins Bay
J. Dragon Lake/ Raven/ Horseshoe
0 50 100 150
Km

Figure 1 – Location of 1989 field work areas.

on the basis of their apparent unconformable relationship with the underlying Archean granitoid gneisses and their subsequent metamorphism during the Hudsonian Orogeny. A broadly defined stratigraphy comprising four main lithological units has been documented for the Wollaston Group (Lewry and Sibbald, 1977 and 1979; Sibbald, 1983). Metamorphic textures and mineral assemblages observed within the Wollaston Domain rocks indicate metamorphic conditions of low to medium pressure, middle amphibolite to lower granulite grade.

The rocks of the Wollaston Domain have been affected by polyphase deformation involving several events of folding, thrusting, and faulting superimposed on an early (D1) penetrative foliation. As a result, most primary features of the Wollaston Group metasediments have been obliterated. The earliest recognized folds (D2 event) are overturned to recumbent, and trend easterly. These folds and the regional gneissosity have been refolded by two nearly orthogonal sets of moderately plunging upright folds. Superimposed on these folding events are several generations of ductile to brittle thrusting and faulting, the latest of which consists of northerly-trending faults and joints.

The Mudjatik Domain is characterized by its non-linear nature, and is composed predominantly of felsic gneisses of granitic to granodioritic-tonalitic composition with subordinate components of supracrustal and late intrusive rocks. The granitoid gneisses are considered, for the most part, to be highly tectonized and reactivated plutonic bodies of Archean age (Lewry and Sibbald, 1980; among others). The characteristic dome and basin pattern of the Mudjatik Domain has been interpreted as produced from the interference of two orthogonal fold sets superimposed upon earlier formed migmatite lobes (Lewry and Sibbald, 1977, 1979, and 1980; Sibbald, 1983). Metamorphic mineral assemblages within the Mudjatik Domain indicate maximum metamorphic conditions of upper amphibolite to lower granulite grade.

a) Key Lake Road

A description of lithological units, structure, and metamorphism has been provided previously (Annesley and Madore, 1988). Part of the 1989 field work was designed to define the characteristics and extent of the boundary zone between the Mudjatik and Wollaston domains, and to determine if the boundary zone is similar to the contacts of Archean granitoid gneiss domes and overlying Aphebian rock types.

New observations in this area may be summarized as follows:

1) Some of the quartzofeldspathic gneisses of uncertain origin (Annesley and Madore, 1988), mapped previously as "meta-arkoses", display one or more of

the following characteristics: a) relict igneous textures, in most instances recrystallized and annealed, b) an overall mineral composition typical of igneous rocks, although mineralogically altered to varying degrees, and c) intrusive field relationships (e.g. intrusive contacts).

2) Fine-grained to coarse-grained granitic layers within these quartzofeldspathic gneisses, interpreted previously as anatectic sweats within meta-arkoses, can be shown to have formed by progressive deformation of an irregular network of pegmatite and aplite veins and dykes within granite-granodiorite gneiss.
3) The transition from relatively undeformed granitoids of the Archean basement complex of the Mudjatik Domain to migmatitic and mylonitic orthogneisses at the boundary of the Mudjatik and Wollaston Domains is continuous and gradational over several hundred metres.
4) Mylonitization and transposition appear to be common features at the boundary of the Mudjatik and Wollaston Domains. It is very common to observe several generations of foliations and structures like sheath and tubular folds, mineral stretching lineations, disrupted folds, and rotated porphyroclasts and porphyroblasts.
5) During peak regional metamorphism, the Archean granitoids and the overlying Wollaston Group metasediments became migmatized to varying degrees. Several generations of thin layers and lenses of leucosomes are present, and these are invariably folded, sheared, and boudinaged.

b) Karin Lake Area

Detailed mapping and sampling was carried out within the northeasterly elongated Karin Lake granite dome and the surrounding supracrustal rocks of the Wollaston Group. Particular attention was given to recently burned over outcrops, since they provide the best exposure. The major lithological units and geological relationships identified by the authors are similar, in most instances, to those reported by Thomas (1979).

Although petrographic and geochemical results are not available at this time, the following stratigraphic sequence was determined (oldest at bottom):

8) Psammitic Gneiss (Meta-Arkose) - in part psammopelitic to calcareous
7) Psammopelitic Gneiss - in part calcareous with subordinate calc-silicate gneiss
6) Garnetiferous Pelitic Gneiss aluminosilicates - in part calcareous, migmatitic, and mylonitic
5) Graphitic Pelitic Gneiss cordierite garnet sillimanite - migmatitic, in part mylonitic; contains lateral facies changes of meta-conglomerate and iron formation
4) Archean/Lower Proterozic Boundary - includes varying proportions of aplite, amphibolite, and pegmatite with subordinate components of Archean granitoids and Aphebian Wollaston Group metasediments, in part strongly migmatitic and/or agmatitic
3) Garnetiferous Granite (Archean) - fine grained to medium grained, relatively homogeneous, weakly foliated to gneissic; in part granulitic (greasy luster) and mylonitic
2) Grey "Marginal Phase" Granitoid (Archean) - fine grained to medium grained, heterogeneous, gneissic; in part migmatitic and mylonitic
1) Archean Granite - fine grained to medium grained, relatively homogeneous massive to moderately gneissic, pink to greyish pink

Other significant observations include the following:

1) Both ortho- and para-gneisses are commonly migmatitic, especially near the Archean/Proterozic boundary. Thin leucosome layers and lenses, in part boudinaged, are a common feature in both.
2) Three major phases of folding have deformed the rocks of the Wollaston Group and the underlying Archean basement: a) F2 - E-W (D2 event) b) F3 - NE-SW (D3 event) c) F4 - NW-SE (D4 event).
3) Deformation makes it difficult to determine the nature of the original Wollaston Group - Archean basement contact. However, the presence of meta-conglomeratic rocks at the eastern edge of the Karin Lake dome suggests an unconformity. In general, the apparently unconformable contact between the Wollaston Group and Archean basement has been transposed into concordance by tectonism.
4) Severe shortening characterizes both Archean basement and Wollaston Group rocks, as implied by tight folding structures.
5) The intensity of deformation increases closer to the contact between the Archean basement granitoids and the overlying Wollaston Group metasediments.
6) Conflicting senses of shear (sinistral and dextral) are shown by kinematic indicators within the Archean/Lower Proterozoic boundary zone, however this phenomenon may be consistent with folding of the boundary zone.

c) Morell Lake and Nekweaga Bay Areas

The authors carried out detailed mapping and sampling in the Morell Lake and Nekweaga Bay areas between kilometre 160 and 220 of the Rabbit Lake road. The geology of the Morell Lake and Nekweaga Bay areas was mapped at a 1:63,360 scale by Chadwick (1966, 1967). Some of the present authors' lithological identifications, stratigraphic relationships, and structural interpretations for this region differ from those of Chadwick (1966, 1967) and other previous workers.

Some preliminary observations of this area are as follows:

1) The Archean basement complex of this map area is composed of a heterogeneous assemblage of plutonic granitoid rocks. This variable suite ranges from fine-grained to coarse-grained, essentially equigranular to inequigranular-porphyritic (porphyroclastic and/or porphyroblastic), relatively massive to strongly gneissic and/or mylonitic granites, granodiorites, and tonalites.
2) All the granitoid rocks, except for pegmatite and aplite veins and dykes, have preceded or accompanied major deformation.
3) Migmatites are common locally, especially in the transitional zone between Archean granitoid gneis-

ses and overlying Wollaston Group pelitic to psammopelitic gneisses.

4) Mylonitization and boudinage also occur in the transitional zone.
5) As along the Key Lake road, some of the quartzofeldspathic gneisses mapped previously as "meta-arkoses" exhibit textural and mineralogical characteristics more typical of highly strained gneissic granitoids. In particular, this is a common feature in outcrops west of Boland Lake and northeast of Hills Lake.
6) The tectonic fabrics observed in the lithological units, especially the pelitic gneisses, suggest three folding events, among which the second appears to have been dominant. Early, E-W trending, recumbent to overturned D2 folds are deformed by two upright folding events. Superposition of these folds on the early folds gave rise to the complex, highly variable interference patterns observed in plan and section views. The ductility contrasts between rock types appears to have been an influential factor on the development of folds and hence on the interference patterns produced.

d) Raven-Horseshoe-Dragon Lakes Area

The authors undertook detailed mapping and sampling in the area extending from Raven and Horseshoe Lakes to Dragon Lake. Outcrop exposure in the area is fair to poor. The area has been previously mapped at reconnaissance and detailed scales (Wallis, 1971; Sibbald, 1979 and 1983). D. Quirt (this volume) of the Saskatchewan Research Council is presently working on the metallogenesis of the Raven and Horseshoe deposits.

A tentative stratigraphy for this area from the Archean basement upwards is as follows (oldest at bottom):

6) Meta-quartzites + sillimanite - in part conglomeratic
5) Psammitic Gneisses - in part calcareous, interlayered with or transitional into meta-quartzites
4) Psammopelitic and Calc-silicate Gneisses - in part migmatitic and mylonitic, transitional into or interlayered with pelitic and psammitic gneisses
3) Pelitic Gneisses + graphite + aluminosilicates + garnet - invariably migmatitic with variable leucosome content, in part mylonitic, locally calcareous
2) Archean/Lower Proterozoic Boundary - transitional zone of variable dimensions, comprising a chaotic mixture of pegmatite, amphibolite, aplite, and migmatite
1) Archean Granitoid Gneisses - heterogeneous, variable composition, in part migmatitic and mylonitic, massive to strongly gneissic

A summary of preliminary field results and interpretations follows:

1) The distribution of rock units, in general, is similar to that reported by Sibbald (1983).
2) The authors have recognized a mylonitic "straight" zone of quartzofeldspathic gneisses, west of Horseshoe Lake. These rocks were originally interpreted as "meta-arkoses", however, less deformed gneisses in this zone retain textural and mineralogical characteristics typical of granitoid gneisses (i.e. orthogneisses).
3) The orthogneisses within the "straight" zone are intensely deformed and strongly migmatitic. Generally, they are fine grained to coarse grained with abundant *lit-par-lit* quartz and feldspar leucosomes and cross-cutting quartz and pegmatite veins. Locally, the orthogneisses are cut by dyke- or sill-like amphibolite sheets, which have also been tectonically disrupted.
4) The contact of the orthogneisses with pelitic to psammopelitic gneisses of the Wollaston Group occurs as a transitional zone consisting of pegmatite, amphibolite, and migmatite (locally agmatitic).
5) As in other parts of the Wollaston Domain, the rocks have been strongly deformed and have been affected by three periods of folding with similar trends to those described earlier.

Note: amphibolite occurs throughout the sequence, however it is more voluminous at the Archean/Lower Proterozoic boundary.

3. Problems and Recommendations

There are many speculations regarding the geological characteristics of the Wollaston Group and the underlying Archean basement. Some of the major problems to be resolved have been reviewed recently by Annesley (1989a). Of these unresolved questions and others put forth, it is the authors' opinion that the identification of the protolith(s) of the quartzofeldspathic gneisses remains the most problematic. The problem of identifying the protolith to quartzofeldspathic gneisses is not new (see Spry, 1969, p279-284; Lewry *et al.*, this voume, for examples). This enigma, in combination with structural and metamorphic complexities, unconformities, and facies changes greatly hinder attempts in refining the lithostratigraphy of the Wollaston Group. The authors recommend, in addition to this present project, that more continuous detailed mapping and core logging, as well as geochronologic and thermobarometric studies, are needed to fully understand the stratigraphy and geological history of the Wollaston Group and its underlying Archean basement.

a) Ongoing and Future Work

Ongoing work in the fall of 1989 includes the following:

1) preparing samples for analytical work; all samples will be processed for thin sections and 250 representative samples will be submitted for major and trace element analysis, REE will be determined on selected samples; and
2) analyzing and interpreting structural data.

Future work in the winter of 1990 will concentrate on:

1) a petrographic study of all outcrop and drill core samples collected from this summer's field work;
2) a geochemical study of representative samples from this summer's field work;

3) construction and correlation of stratigraphic sections, in particular across the Archean/Aphebian boundary;
4) correlation and integration of petrographic, structural, lithostratigraphic and geochemical results with existing stratigraphic and lithogeochemical data (Annesley, 1989a and 1989b; and confidential company files) of the Wollaston Group and its underlying Archean basement; and
5) Interim Report.

Potential field areas selected for the summer of 1990 are:

1) Trout Narrows and surrounding area, Wollaston Lake
2) Highrock Lake
3) Michael Lake
4) Harrison Peninsula/Ivison Bay/Pow Bay/Ashley Peninsula
5) Selected drill hole sites.

4. Acknowledgements

We gratefully acknowledge the following researchers for valuable discussions and taking time in the field with us: C. Keller, K. Kogler, and B. Tan of Uranerz Exploration and Mining Ltd.; B. Duncan, B. McGill, P. Ogryzol, G. Ruhrmann, and D. Studer of Cameco; F. Hopfengartner and H. Quarch of Interuranium Canada Ltd.; S. Lavoie of Cogema; T.I.I. Sibbald of the Saskatchewan Energy and Mines; and D. Quirt of the Saskatchewan Research Council. The senior author wished to thank V. Sopuck (Cameco) and K. Kogler (Uranerz) for input into field logistics and operations.

Funding for this work was provided by Cameco, CEGB (Canada) Ltd., Cominco Ltd., Interuranium Canada Ltd., PNC Exploration (Canada) Co. Ltd., Uranerz Exploration and Mining Limited, the Saskatchewan Geological Survey, and the Saskatchewan Research Council.

Excellent fixed wing support and expediting services, respectively, were provided from Missinipe by Garry Thompson and family of Osprey Wings Ltd. and Thompson's Camps, and from Points North by Athabasca Airways and Points North Freight. The authors also wish to thank Cameco, Cigar Lake Mining Corporation, Interuranium Canada Ltd., and Uranerz Exploration and Mining Ltd. for their hospitality while visiting drill sites.

Critical review of this manuscript by T.I.I. Sibbald is greatly appreciated. Any speculative interpretation remains the sole responsibility of the authors.

5. References

Annesley, I.R. (1989a): The Wollaston Group and its underlying Archean basement in Saskatchewan: an update; Sask. Res. Coun., Pub. R-855-5-E-89, 86p.

Annesley, I.R. (1989b): Whole-rock geochemistry from samples of Aphebian Wollaston Group metasediments and underlying Archean granitoid gneisses; Sask. Res. Coun., Pub. R-855-6-E-89, 70p.

Annesley, I.R. and Madore C. (1988): The Wollaston Group and its underlying Archean basement in Saskatchewan: preliminary report; *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4.

Annesley, I.R. and Madore, C. (1989): A re-examination of the Wollaston Group and its underlying Archean basement in northern Saskatchewan; Geol. Assoc. of Can./Miner. Assoc. of Can., Program with Abstracts, pA39.

Chadwick, B. (1966): The geology of the Nekweaga Bay area (west half), Saskatchewan; Sask. Dep. Miner. Res., Rep. 109 40p.

Chadwick, B. (1967): The geology of the Morell Lake area (west half), Saskatchewan; Sask. Dep. Miner. Resour., Rep. 116, 24p.

Lewry, J.F. and Sibbald, T.I.I. (1977): Variation in lithology and tectonometamorphic relationships in the Precambrian basement of northern Saskatchewan; Can. Jour. of Earth Sci., v14, p1453-1467.

Lewry, J.F., Sibbald, T.I.I. (1979): A review of the pre-Athabasca basement geology in northern Saskatchewan; *in* Parslow, G.R. (ed.), Uranium Exploration Techniques, Sask. Geol. Soc., Spec. Publ. 4, p19-58.

Lewry, J.F. and Sibbald, T.I.I. (1980): Thermotectonic evolution of the Churchill Province in northern Saskatchewan; Tectonophysics, v68, p45-82.

Lewry, J.F., Sibbald, T.I.I. and Schledewitz, D.C.P. (1985):

Variation in character of Archean rocks in the western Churchill Province and its significance; *in* Ayres, L.D., Thurston, P.C., Card, K.D. and Weber, W. (eds.), Evolution of Archean Supracrustal Sequences, Geol. Assoc. Can., Spec. Pap. 28, p239-261.

Sibbald, T.I.I. (1979): NEA/IAEA test area: basement geology; *in* Summary of Investigations 1979, Sask. Geol. Surv., Misc. Rep. 79-10, p77-85.

Sibbald, T.I.I. (1983): Geology of the crystalline basement, NEA/IAEA Athabasca test area; *in* Uranium Exploration in Athabasca Basin, Geol. Surv. Can., Pap. 82-11, p1-14.

Spry, A. (1969): Metamorphic Textures; Pergamon Press, New York, 352p.

Thomas, D.J. (1979): Uranium metallogenic studies, "pegmatite" prospect geology; *in* Summary of Investigations 1979, Sask. Geol. Surv., Misc. Rep. 79-10, p86-95.

Wallis, R.H. (1971): The geology of the Hidden Bay area, Saskatchewan; Sask. Dep. Miner. Resour., Rep. 137, 75p.

Mineral Deposit Studies: Raven-Horseshoe Uranium Deposit, Preliminary Report

D.H. Quirt[1]

Quirt, D.H. (1989): Mineral deposit studies: Raven - Horseshoe uranium deposit - preliminary report; *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

Investigation of the geochemistry, mineralogy, and uranium metallogenesis of the Raven-Horseshoe deposit was initiated in 1989. This report gives background information on the area and includes the preliminary results of field work and x-ray diffraction (XRD) mineralogical investigations of the clay mineralogy of the host-rock alteration assemblage.

To date, studies on the metallogenesis and host-rock alteration of this deposit have not been carried out, although a report based on field mapping and drill core logging and assaying (Bagnell, 1978) was produced by the original property owners, Gulf Minerals. The property is now held by Cameco.

1. Objectives

The major goal of this investigation is to elucidate the geology of the Raven-Horseshoe uranium deposit. Comparisons will be made with other basement-hosted unconformity-type deposits, and possible exploration strategies for these deposits will be evaluated with respect to the findings of the study. Investigations will encompass the following:

1) evaluation of the geology and geological setting of the deposit;
2) establishment of the mineralogy of the host rocks, mineralization and associated host-rock alteration;
3) evaluation of the clay mineralogy of the host-rock alteration assemblage;
4) evaluation of the geochemical signature(s) of the mineralization and associated host-rock alteration; and
5) determination of stable and radiogenic isotopic characteristics of gangue and ore minerals, as required.

2. General Geology

The deposit is located in the Wollaston Domain, a lithostructural subdivision of the Cree Lake Ensialic Mobile Zone of the Trans-Hudson Orogen. This region has undergone a complex history of metamorphism and deformation as a result of the Early Proterozoic-Hudsonian orogeny. The Wollaston Domain is a northeast-trending linear belt of highly deformed Aphebian supracrustal rocks that rest on Archean granitoid gneisses. The metamorphic grade generally ranges from the upper amphibolite to granulite facies. The supracrustals, in the study area have been as described previously consisting of three main units (Wallis, 1971; Lewry and Sibbald, 1977, 1979; Sibbald, 1983; Annesley, 1989):

1) A metasedimentary unit of pelitic to psammopelitic gneisses interlayered with metaquartzite, psammitic gneiss, calc-silicate gneiss, and marble. Graphite is commonly found within the basal lithologies which overlie (probably unconformably) the granitoid gneiss basement.
2) A thick metasedimentary unit of clastic psammitic gneisses which are variably calcareous, containing interlayers of calc-silicate gneiss, marble and pelitic gneiss.
3) An amphibolite-metaquartzite unit containing interlayers of calcareous psammitic to psammopelitic gneisses and graphitic pelitic gneisses.

The latter unit, described by Wallis (1971) as the Hidden Bay assemblage, is the host for the Raven-Horseshoe deposit (Bagnell, 1978).

The Wollaston Domain has been affected by five phases of deformation superimposed on an early penetrative foliation (D1). The first three major deformational events consisted of east-northeast-trending folding (D2) followed by northeasterly-trending folding (D3), followed by northwesterly-trending open folding and jointing (D4). The northeast-trending structures were later reactivated (D5) with resultant thrust faulting and shearing that gave rise to the characteristic northeasterly structural grain of the Domain (Wallis, 1971). The last phase of deformation (D6) consisted of northerly-trending sinistral faulting and jointing that cross-cut the earlier structures. These faults appear to be continuations of the Tabbernor fault system (Sibbald, 1983; Annesley, 1989).

The Helikian Athabasca Group occurs approximately 4 to 10 km north and 10 km west of the deposit area, and is exposed in isolated outliers to the south and east. It comprises sandstones and basal conglomerates of the lower Manitou Falls Formation (Ramaekers, 1983). Based on elevations of the sub-Athabasca Group unconformity at the above locations, it is estimated that the present-day erosional level of the Aphebian rocks in the immediate Raven - Horseshoe deposit area is ap-

---

(1) Saskatchewan Research Council, Saskatoon, Saskatchewan

proximately that of the plane of the eroded unconformity. As there is up to 80 m of original pre-Athabasca relief in this area (Wallis, 1971), the presently subcropping Aphebian metaquartzite may have been within this distance of the sub-Athabasca unconformity.

3. Local Geology

The Raven-Horseshoe deposit is located close to the western shore of Wollaston Lake, approximately 6 km south-southeast of the Rabbit Lake mill complex. The Raven deposit was discovered in 1972 while the Horseshoe deposit discovery followed in 1974. Both deposits lie between 15 and 300 m below surface. The two zones were originally thought to represent separate uranium deposits, but as they occupy identical locations with respect to geological structure, show close similarity in style of mineralization, and are connected by subeconomic, sporadic uranium mineralization, the zones are now recognized as a single deposit. Total indicated and inferred reserves are approximately ten million kilograms U_3O_8 based on a 0.03 percent cutoff (Bagnell, 1978).

Bagnell (1978) describes the lithologies that underlie the Raven - Horseshoe deposit as pelitic gneisses and "meta-arkose" and those that host the deposit as feldspathic quartzites and calcareous metasediments, all belonging to the Hidden Bay assemblage of Wallis (1971). The principal host rocks to the uranium mineralization are granoblastic, medium- to coarse-grained, feldspathic metaquartzites that are composed of quartz and feldspar with minor biotite and sillimanite. The quartz content of this unit varies from greater than 90% (metaquartzite) at the apparent top, through 75-90% quartz (feldspathic metaquartzite), to less than 75% (arkosic metaquartzite) at the apparent bottom. This unit grades structurally upwards into calcareous pelitic gneiss and structurally downwards into feldspathic gneiss ("meta-arkose" of Bagnell, 1978 and Wallis, 1971) and amphibole gneiss.

The calcareous pelitic gneiss consists of quartz, plagioclase, hornblende, biotite, and characteristically, diopside. Minor quantities of carbonate and sulfide minerals are present locally, as are minor quantities of uranium mineralization located near the contact with the metaquartzite. This unit is medium grained, well foliated, greenish, generally banded, and contains trace amounts of graphite.

The feldspathic and/or amphibolitic gneiss physically below the metaquartzite contains both plagioclase and potassic feldspar, subordinate quartz, and varying amounts of biotite and hornblende. Very minor quantities of uranium mineralization are found in this unit. Toward the base of the unit, the mineralogy becomes amphibolitic with varying amounts of biotite and feldspar and little to no quartz. Both the feldspathic and amphibolitic rocks are layered, well foliated, and are coarse to medium grained.

At least three generations of pegmatite are present within the deposit area. These correspond to Wallis' (1971) P1, P2, and P3 pegmatites. The earliest pegmatites, P1, are leucosomes found primarily in migmatitic biotitic pelitic gneiss, but are present in all rock units.

Second generation pegmatites (P2) cut P1 pegmatite material but are also folded and boudinaged by the D2 deformation (Wallis, 1971). These pegmatites contain feldspar and quartz with hematite and tourmaline. Hematite is ubiquitous, often imparting a purplish-red spotty appearance to the pegmatite.

The third generation of pegmatites (P3) cross-cut P1 and P2 and are relatively undeformed, not being affected by the D2 event. These pegmatites have been encountered in drill core in widths up to 15 m. The mineralogy is generally simple with feldspar and quartz but large biotite flakes are common, especially near the contact, and radial clusters of tourmaline are intergrown with quartz in places.

The deposit area exhibits a complex interplay of folding and faulting; the folds containing the deposit being upright and horizontal, northeasterly-trending D3 structures(Bagnell, 1978). Previous interpretations of the geology have identified these folds as an anticline-syncline pair, known as the Raven syncline and the Horseshoe anticline. Folding in the area is disrupted by numerous shears and faults, which are parallel to the major northeasterly and southerly fracture trends. Senses of shear are variably left- or right-hand while offsets are minor, in the order of a few hundred metres (Bagnell, 1978). The major control for the mineralization is by these shears and fracture zones. Metaquartzite intersected by the northerly set of faults is strongly fractured, hematized and silicified, while the northeasterly-trending structures are associated with argillic alteration (Sibbald, 1983).

4. Mineralization and Host-rock Alteration

The Raven-Horseshoe deposit contains two separate ore zones separated by a narrow zone of very low grade mineralization that is essentially a geochemical enrichment. Widths of the mineralized zones are variable, but average about 90 m. Mineralization extends from near the subcrop surface to over 330 m below subcrop and is structurally controlled, occurring as fracture and fault fillings, but rarely as impregnations in the host rock.

Ore mineralogy is simple, consisting of pitchblende [UO_2] and boltwoodite [$K_2(UO_2)_2(SiO_3)_2 \cdot 5H_2O$], a uranophane-group mineral. Coffinite [$USiO_4$] is present only in trace amounts. Ni-Co arsenides are notably absent and only traces of oxidized Cu mineralization have been noted. Small quantities of base metal sulphides are present throughout the host rocks either as disseminations or as fracture coatings. Pyrite is the most common, but still only constitutes less than one percent of the rock. Oxidized chalcopyrite and galena have been noted in trace amounts, and pyrrhotite is reportedly present (Bagnell, 1978). Most of the sulphides have been oxidized, especially those found in fractured metaquartzite where hematite after pyrite is common.

Mineralization is strongly fracture-controlled with disseminated mineralization rarely seen. Host-rock alteration associated with the mineralization consists of hematization and clay mineral development, however, the background clay mineralogy of the host metaquartzite is complex. Fresh grey metaquartzite contains minor quantities of trioctahedral Fe-Mg chlorite with lesser illite/sericite. Variably hematitic and bleached, purplish to buff, unmineralized metaquartzite with clay-altered feldspars reveals an assemblage of di,trioctahedral aluminous chlorite similiar to that found in the Athabasca Group (Hoeve and Quirt, 1984) with subordinate illite, swelling chlorite, and rare kaolinite. Paleoweathered metaquartzite tends to contain kaolinite with illite at the expense of di,trichlorite and is hematized, being purplish in color. Limonite (ferrihydrite) is commonly found as fracture coatings and impregnations in the clay-altered metaquartzite,but is only rarely found as fracture coatings in fresh metaquartzite. Mineralized metaquartzite contains an assemblage of Fe-Mg trioctahedral chlorite (structurally different from that found in the fresh rock), illite, and minor amounts of swelling chlorite, kaolinite and mixed-layer illite-smectite. There is an intimate relationship between uranium mineralization and hematization, however, recent meteoric waters have partially converted hematite to limonite.

5. Acknowledgements

The author would like to thank the following geoscientists for their suggestions and discussions concerning the Raven-Horseshoe deposit and the geology of the area: I.R. Annesley (SRC), T.I.I. Sibbald (SEM), and D. Studer (Cameco).

SEM and Cameco are also thanked for jointly funding this project.

6. References

Annesley, I.R. (1989): The Wollaston Group and its underlying Archean basement in Saskatchewan: An update; Sask. Res. Coun. Pub. R-855-5-E-89, 86p.

Bagnell, B.A. (1978): Gulf Minerals Canada Limited report on the Raven-Horseshoe deposit, Reindeer Mining Division, ML 5220, northern Saskatchewan; unpubl. rep., 14p.

Eldor Resources Limited. (1987): The Eagle Point uranium deposits, northern Saskatchewan; *in* Gilboy, C.F. and Vigrass, L.W. (eds.), Economic Minerals of Saskatchewan, Sask. Geol. Soc., Spec. Publ. No. 8, p78-98.

Gregory, A.F. (1983): Interpretative geological mapping as an aid to exploration in the NEA/IAEA Athabasca Test Area; *in* Cameron, E.M. (ed.), Uranium exploration in Athabasca Basin, Saskatchewan, Canada, Geol. Surv. of Can., Pap. 82-11, p171-178.

Hoeve, J. and Quirt, D.H. (1984): Mineralization and host-rock alteration in relation to clay mineral diagenesis and evolution of the middle-Proterozoic Athabasca Basin, northern Saskatchewan, Canada; Sask. Res. Coun., Tech. Rep. No. 187, 187p.

Lewry, J. and Sibbald, T.I.I. (1977): Variation in lithology and tectono-metamorphic relationships in the Precambrian basement of northern Saskatchewan; Can. Jour. Earth Sci., v14, p1453-1467.

_______ (1979): A review of the pre-Athabasca geology in northern Saskatchewan; *in* Parslow, G.R. (ed.), Uranium Exploration Techniques, Sask. Geol. Soc., Spec. Publ. 4, p19-58.

Quirt, D.H. (1989): 1989 Field Notes: (A) Raven-Horseshoe sampling program (SEM), (B) Eagle Point fill-in sampling program (Cameco); Sask. Res. Coun., Publ. No. R-1230-7-E-89, 31p.

Ramaekers, P. (1983): Geology of the Athabasca Group, NEA/IAEA Athabasca Test Area; *in* Cameron, E.M. (ed.), Uranium in Athabasca Basin, Saskatchewan, Canada, Geol. Surv. of Can., Pap. 82-11, p15-25.

Sibbald, T.I.I. (1983): Geology of the crystalline basement, NEA/IAEA Athabasca Test Area; *in* Cameron, E.M. (ed.), Uranium in Athabasca Basin, Saskatchewan, Canada, Geol. Surv. of Can., Pap. 82-11, p1-14.

Wallis, R.H. (1971): The geology of the Hidden Bay area, Saskatchewan; Sask. Dep. of Min. Resour., Rep. No. 137, 74p.

A Reinterpretation of Lake Sediment Geochemistry in the NEA/IAEA Athabasca Test Area

Michel Mellinger[1]

Mellinger, M. (1989): A re-interpretation of lake sediment geochemistry in the NEA/IAEA Athabasca test area; *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

The NEA/IAEA Athabasca Test Area, located at the eastern edge of the Athabasca Basin of northern Saskatchewan, was chosen in 1979/80 for the purpose of testing a variety of exploration techniques for Athabasca Basin unconformity-type uranium deposits (Cameron, 1983). Organic-rich lake sediments and lake waters were collected in the test area in 1977 and 1979. In addition to chemical data, field observations coded in the 1977 and 1979 data files included: sample colour, lake area and depth, surrounding relief, potential contamination resulting from exploration activity, and underlying bedrock. The chemical and underlying bedrock data were interpreted by Coker and Dunn (1981, 1983), but other field data were not considered. In addition to detecting samples with anomalously high element concentrations and relating them to known uranium deposits, these authors noted spatial trends in the data which may reflect known northeasterly basement lithological trends and glacial geology. They also examined geochemical associations by plotting a map of samples with concentrations higher than the 90th percentile value for any element.

In the present project the field and geochemical data were examined using multivariate data analysis. This paper briefly summarizes the results obtained. A more comprehensive report is available (Mellinger, 1989) and a map showing the location of newly identified uranium anomalies can be obtained from the Saskatchewan Research Council.

1. Field and Analytical Data

The following data were extracted from the 403 samples collected in 1977 and 1979: sample number, UTM coordinates, field variables (underlying bedrock, lake area, lake depth, relief) and lake sediment chemistry (U, Zn, Cu, Pb, Ni, Co, Ag, Mn, As, Mo, Fe, LOI). To this was added: drainage basin, drainage order, presence of known mineralization in the vicinity, and Quaternary geology.

Underlying bedrock geology, coded in the initial data file, was modified to comply with the four basement lithologies described by Sibbald (1980). Lake area was kept in its original form, but lake depth, initially coded in whole metres (range: 1 m to 18 m), was recoded after examination of a percentile cumulative plot, into the following depth categories: 1 m, 2 m, 3 m, 4-5 m, 6-7 m, 8-to-12 m, and 15-to-18 m.

2. Correspondence Analysis of the Field Variables

Field observations are qualitative variables, either nominal (underlying bedrock, drainage basin, Quaternary geology) or ordinal (lake area and depth, relief). The data, from the table of 403 sample records with 28 completely disjunctive variables, were each submitted to correspondence analysis (Mellinger 1987). From this analysis clear field variable patterns can be identified that show non-linear relationships.

Lake morphology parameters show consistent relationships. For example, lake depth increases with increasing lake area and surrounding relief. The distribution of lakes with given characteristics is not homogeneous, however, with respect to drainage basin, Quaternary geology, or underlying bedrock. Thus even if lake morphology affects the chemical characteristics of their sediments to a significant degree, it can still be expected that lake sediment chemistry will display regional patterns which also result from the influence of one or more of drainage basin, Quaternary geology, and underlying bedrock.

3. Lake Sediment Chemistry

Correspondence analysis of the geochemical variables produced the following results:

1) The dominant pattern is a negative correlation between Mn and a group of elements comprising LOI (essentially organic content of the sediments) and the metals Zn, Cu, Ni, and Ag (factor 1).
2) Zn, Cu, Ni, and Ag are positively correlated themselves, meaning that these metals are generally associated with organic matter in the lake sediments.
3) A clear Fe-As-(Mo) trend also emerges, with minor residual Zn versus LOI negative correlation and Co contribution (factors 2 and 3).
4) A uranium, Ni, and Cu association (factor 4) is recognized which extracts a residual U trend ("residual" because the 23 samples with U 20 ppm were not included in these calculations).

Applying a threshold to coordinates along this fourth factor permits the recognition of an additional 22 samples which are anomalous in uranium, bringing the number of uranium anomalies to a total of 45 samples.

---

(1) Saskatchewan Research Council, Saskatoon, Saskatchewan

4. New Uranium Anomalies

When sample coordinates along factor F4 and initial U concentrations are plotted together (Figure 1), two subpopulations of samples appear. One indicates a clear inverse correlation between increasing U(ppm) and the value of the F4 coordinate. These samples are anomalous on either axis, generally 20 ppm U and 250 F4 coordinate, and the subpopulation is univariate anomalous. The other subpopulation closer to the F4 axis also defines an inverse correlation between U(ppm) and the value of the F4 coordinate; however, the component samples cannot all be identified as anomalous on the basis of U(ppm) alone, in particular for U 10 ppm. Their anomalous character is illustrated by an F4 coordinate of -250. These samples form a multivariate anomalous subpopulation which requires extraction of other multivariate patterns (along factors F1 to F30 before it can be recognized. The subpopulation represents the new set of lake sediment U anomalies in the survey area.

5. Field Variables and the Chemical Space

When variables representing field observations are projected into the chemical factor space, it is clear that environment has a significant influence on lake sediment chemistry. Lake morphology affects the type of sediment encountered and therefore also the sediment chemical signature. Organic-rich sediments in contrast to those rich in Mn-oxides occur in relatively small, shallow lakes surrounded by gentle relief. Some drainage basins show an affinity for particular chemical trends. The underlying bedrock appear to influence sediment type; for example, Mudjatik basement underlies lake sediments of both medium and high organic content, whereas Athabasca sandstone underlies mostly organic-rich lake sediments.

The Quaternary geology displays one chemical relationship that is particularly interesting: glacio-fluvial sediments are associated with the Fe-As-(Mo) trend, which explains why no particular drainage basin relates to the

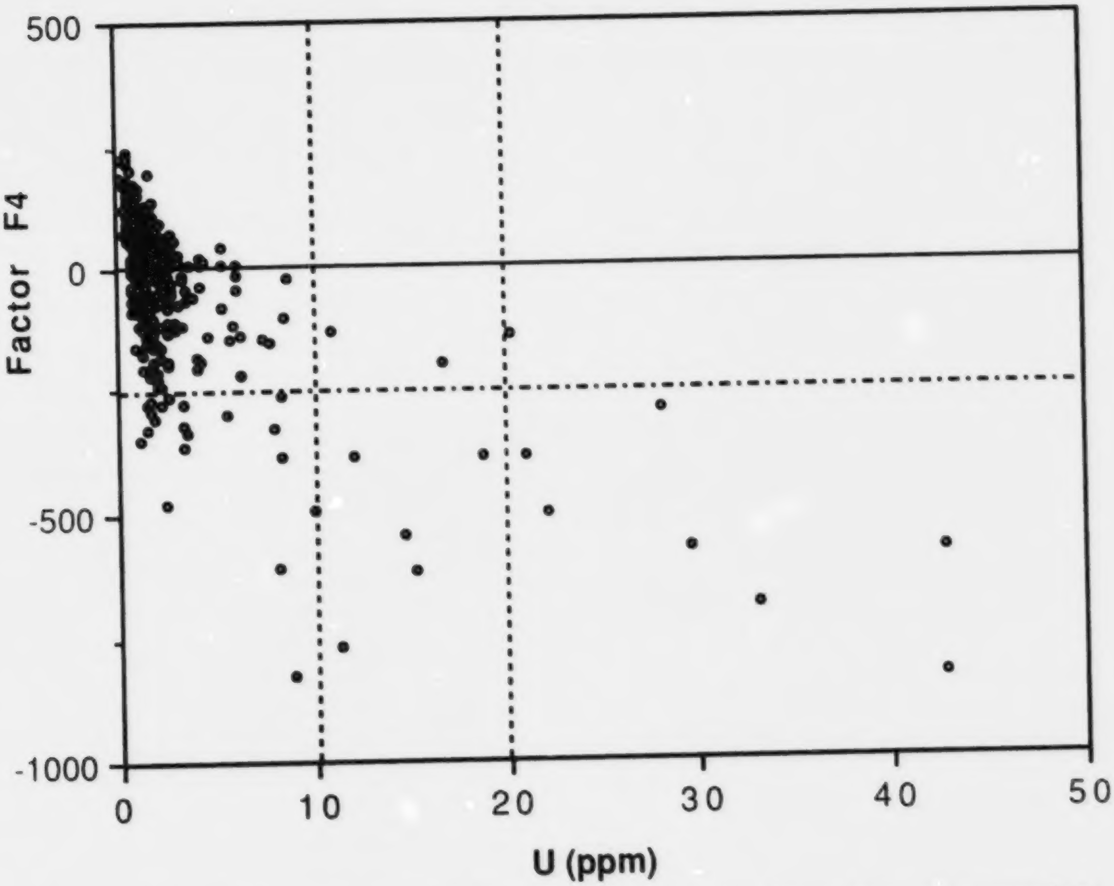


Figure 1 - Comparison of factor coordinates along F4 (U anomalous trend) and analyzed U(ppm). Anomalous factor coordinates are towards negative values, with -250 as anomaly threshold (stippled line).

anomalies in the chemical space. The Fe-As-(Mo) anomalies may result from sub-glacial rivers transporting sediments into the survey area.

6. Conclusions

Re-interpretation of the data has demonstrated that:

1) field variables can greatly influence the lake sediment chemistry,
2) descriptive multivariate data analysis (in particular correspondence analysis) extracts clear information from complex data, both qualitative (field observations) and quantitative (chemistry),
3) new uranium anomalies can be apparent which might not be identified simply on the basis of U concentration, and
4) the majority of Fe-As-(Mo) anomalies are related to glacio-fluvial sediments extending mostly from Dawn Lake to the southwest. This trend was noticed by Coker and Dunn (1983), but not identified as being related to glacio-fluvial features probably due to the lack of field data.

7. References

Cameron, E.M. (1983): Uranium exploration in Athabasca Basin, Saskatchewan Canada; E.M. Cameron (ed.), Geol. Surv. Can., Pap. 82-11, 310p.

Coker, W.B. and Dunn, C.E. (1981): Lake water and sediment geochemistry, NEA-IAEA Athabasca Basin - Wollaston Lake, Test Area (64L, 74I), Saskatchewan, Canada; Geol. Surv. Can., Open File 779.

__________ (1983): Lake water and lake sediment geochemistry, NEA/IAEA Athabasca Test Area; *in* Uranium Exploration in Athabasca Basin, Saskatchewan, Canada; E.M. Cameron (ed), Geol. Surv. Can., Pap. 82-11, p117-125.

Mellinger, M. (1987): Correspondence analysis: The method and its application; Chemometrics and Intelligent Laboratory Systems, v2, p61-77.

__________ (in press): Multivariate patterns of field information and geochemistry in a regional lake sediment survey; the NEA/IAEA Athabasca Test Area revisited; *in* Proceedings of the Colloquium "Statistical Applications in the Earth Sciences," Geol. Surv. Can.

Sibbald, T.I.I. (1980): NEA/IAEA Test Area: Sub-Athabasca Group, basement geology; *in* Summary of Investigations 1980, Sask. Geol. Surv. Misc. Rep. 80-4, p57-58.

Field Relationships and Kinematic Indicators in the Virgin River Shear Zone

James Carolan[1] and Kenneth D. Collerson[1]

Carolan, J. and Collerson, K.D. (1989): Field relationships and kinematic indicators in the Virgin River Shear Zone; *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

The Virgin River Shear Zone (VRSZ), an Early Proterozoic transcurrent fault located in northwest Saskatchewan, is defined by a 4 km-wide belt of mylonitic rocks derived from metamorphosed plutonic, volcanic and sedimentary protoliths. The zone separates dominantly granulite facies quartzofeldspathic gneisses of the Western Granulite Domain from lower grade supracrustal rocks and felsic gneisses of the Virgin River Domain to the east. Previous reconnaissance mapping of the shear zone was carried out by Sibbald (1973) and Lewry (1974), Wallis (1970), and Johnson (1968). The present study, a 1:20 000 scale mapping project, is being undertaken to evaluate kinematic indicators in the Virgin River Shear Zone and account for its role in the tectonic superposition of the Rae and Hearne Provinces (Hoffman, 1988).

1. Regional Setting

The VRSZ (Lewry and Sibbald, 1977), the Black Lake Shear Zone (Gilboy, 1980) and the Tulemalu Fault Zone (Tella and Eade, 1986) are components of what is now collectively called the Snowbird Tectonic Zone (Hoffman, 1988). This major zone, extending 3 000 km from the Rocky Mountains in southern Alberta to the Hudson Strait in the Northwest Territories separates the Rae and Hearne Provinces. The zone has been previously been interpreted as an intracontinental reactivation structure resulting from Hudsonian thermotectonism (Lewry and Sibbald, 1977) or as a crustal suture (Hoffman, 1988).

In the Careen Lake area (Figure 1), the VRSZ forms a 4 km-wide northeast-trending complex of interbanded protomylonites and ultramylonites derived predominantly from the Western Granulite Domain and, to a lesser extent, from the Virgin River Domain.

2. Field Characteristics West of the Shear Zone

Western Granulite Domain gneisses west of the shear zone have been derived from a variety of protoliths, including granite, granodiorite, tonalite, gabbro, anorthosite and complexly intercalated supracrustals. Mineral assemblages indicate that these rocks experienced a granulite facies event which was later overprinted by lower amphibolite to greenschist facies metamorphism. Recognition that the intensity of this overprint increases with proximity to the shear zone suggests that the retrogressive metamorphic event may have been contemporaneous with movements along the shear zone.

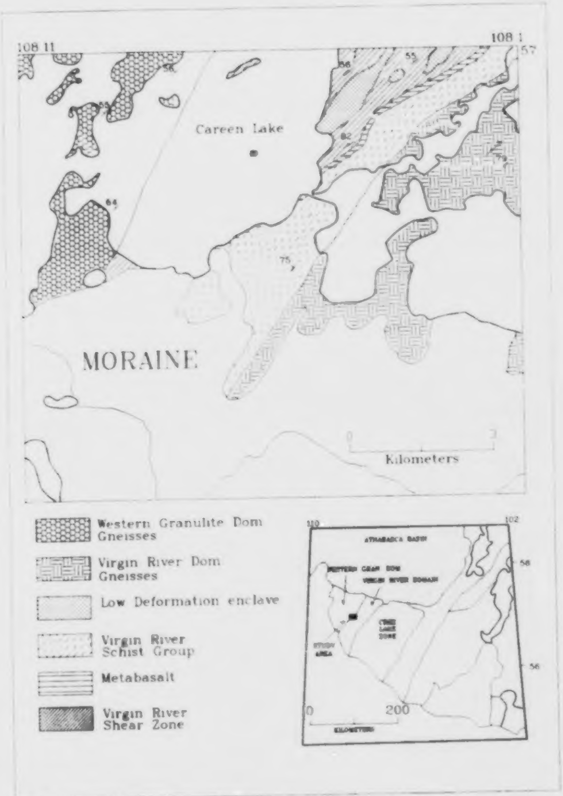


Figure 1 - Geological sketch map of the Virgin River Shear Zone at Careen Lake.

Lakeshore outcrops along the western margin of the area indicate a progressive dextral rotation and flattening of regional gneissic layering with proximity to the shear zone (Carolan, Crocker and Collerson, this volume). The same sense of rotation can be recognized on a plot of aeromagnetic highs and lows in the area. (Sibbald and Lewry, 1977)

---

(1) Earth Sciences Board, University of California, Santa Cruz, California

3. Field Characteristics East of the Shear Zone

Rocks of the Virgin River Domain consist of amphibolite to granulite grade felsic gneisses flanked on the western margin by the Virgin River Schist Group (Johnson, 1968; Wallis, 1970). The felsic gneisses are composed of granite, tonalite, granodiorite, and minor amphibolite.

The well exposed Virgin River Schist Group (VRSG) consists of psammopelitic metasediments and possible metatuffs bounding a thin continuous unit of metabasalt. The VRSG is cut by tourmaline-bearing pegmatites but lacks the mafic dykes common in the shear zone. The contact between the VRSG and the main mylonite zone is gradational. The progressive rotation of fabric recognized on the western margin of the shear zone was not recognized on the eastern margin.

4. Field Characteristics of the Shear Zone

The VRSZ is defined by an approximately 4 km-wide northeast-trending belt of mylonitic rock derived from plutonic, volcanic and sedimentary sources. Plutonic components include granodiorites, gabbros, tonalites, and augen granites. The volcanic component is a relatively thin sequence of pillow basalts at the eastern edge of the shear zone. Metasedimentary mylonites, which occur intermittently throughout the shear zone, are compositionally similar to rocks of the VRSG to the east, indicating that part of the VRSG has been incorporated into the mylonite zone. Contacts between these units and the plutonic and volcanic components of the shear zone are sharp and planar, probably due to transposition of units during ductile deformation. Mineral assemblages within the shear zone indicate that greenschist to lower amphibolite facies metamorphism prevailed.

Most rocks in the shear zone appear to have been derived from Western Granulite Domain gneisses and less from the Virgin River Domain. Of particular interest are a body of nepheline syenite and a cross-cutting mafic dyke swarm:

a) Nepheline Syenite

The nepheline syenite crops out as a 1000 m long lensoid body lying in a low shear enclave of the main mylonitic zone. The body strikes parallel to the shear zone and has a complex contact with the surrounding mylonite. Where significant shear has taken place within the nepheline syenite, fluids from the main mylonite zone have precipitated quartz, producing anamolous quart-rich zones.

b) Mafic Dyke Swarm

The mafic dyke swarm in the shear zone was previously recognized by Wallis (1970) along a section of the shear zone north of the present study area and identified regionally by Macdonald (1980). The dyke swarm, which generally parallels the trend of the shear zone, comprises mafic mylonites in the main shear zone and relatively undeformed gabbros in areas of low strain. In many places in the areas of low strain the gabbros preserve relict igneous textures and cross-cut the gneisses.

c) Strain Features

Strain variation within the VRSZ is very complex and characterized by a complicated intercalation of low strain enclaves within the main mylonite zone. The low strain enclaves, generally composed of granodioritic-tonalitic gneiss with subordinate cross-cutting augen gneiss and gabbros, are kilometre-scale lensoid bodies exhibiting primary intrusive relationships. Contacts between these zones and the surrounding mylonite range from relatively simple textural gradations to a complex series of flattened gneiss-mylonite interbands.

Observations of grain morphologies indicate that flattening in the main mylonite zone was due to a significant component of pure as well as simple shear.

5. Structural Geology

a) Folding

At least four episodes of folding have been recognized in the VRSZ and the Virgin River Domain. Rare F1 folds are small, rootless and isoclinal. They are refolded by northeast-plunging folds (F2), which are tight to isoclinal with steep to shallow plunges, and are recognized at both mesoscopic and macroscopic scales. The F2 folds are in turn refolded by northwest-trending F3 folds, which have only been recognized at a mesoscopic scale.

Postmylonite deformation (D4) includes localized reverse kink banding and box folding of the mylonitic fabric.

b) Faulting

Faulting was produced by both ductile and brittle deformation. The dominant fabric within the shear zone preserves a history of dextral displacement due largely to ductile deformation. Later brittle faulting is both oblique and parallel to the main mylonitic fabric. Along the mylonitic fabric plane, pegmatite and granitic dykes show dextral offset.

Two conjugate brittle fault sets are recognized in the area:

1) oriented at 040° to 080° with near vertical dips, they show normal dextral offset and are commonly associated with fault breccia and drag folds; and
2) faults oriented at approximately 340° to 360° exhibit normal sinistral offset. These conjugate faults are interpreted as resulting from brittle failure of more competent layers during extension along the main shear zone.

c) Foliation in the VRSZ

The dominant penetrative foliation of the mylonite zone (S3) is believed to have formed by the reorientation of an earlier foliation (S1) which in places is preserved as an internal fabric within asymmetric pinch and swell structures. An oblique fabric (S2) is also commonly preserved as a component in C-S fabrics.

The dominant foliation (S3) dips to the northwest at 35°-80°, with most dips at 55°-70°. Mineral lineations are defined by aligned hornblende and feldspar grains and plunge northeast at 5°-45°, averaging approximately 20°. The plunge of the lineation suggests that the major component of motion is strike-slip with a minor east-side-up dip-slip component.

d) Kinematic Indicators

Observed kinematic indicators include: rolling structures, asymmetric pinch-and-swell, asymmetric folds, C-S structures, and offset veins and dykes. Although most asymmetric grains are somewhat ambiguous, all the rolling structures possessing a clear asymmetry consistently show a Z-type geometry, indicative of a dextral shear sense (Van Den Dreissche,1987). The observed rolling structures are typically feldspar porphyroblasts with asymmetric tails.

Asymmetric pinch-and-swell structures recognized in the area are of the Type 2 class of Hamner (1986), and occur in layers of amphibolite surrounded by a less competent quartzofeldspathic matrix. Shear along the plane of extension has commonly produced an antithetic rotation of the swell section of the structure. Observations of such rotated structures in the area indicate that the sense of shear was dextral.

C-S structures observed in the area are largely ambiguous. Near the margins of the shear zone a sinistral shear sense is largely indicated, but in the core of the shear zone the shear sense is consistently dextral.

Late movement in the shear zone is indicated by asymmetric folds and offset pegmatitic dykes. The asymmetric folds are fairly common and exhibit a consistent dextral shear sense. Late dykes cut the penetrative mylonitic foliation at a high angle and are dextrally offset within the plane of the mylonitic fabric. This observation indicates that there were multiple periods of fault movement along the VRSZ.

6. Interpretation

Gross similarities in rock types and deformation style suggest that the VRSZ may have resulted from processes analogous to the Cenozoic Eurasian-Indian tectonic closure. Recognizing the similarities between Himalayan deformation processes and the plasticity problem of plane indentation, Molnar and Tapponier (1984) were able to develop a reasonable model for Himalayan tectonic processes. We believe a similar analogy can be drawn for the Early Proterozoic Wopmay and Trans-Hudson Orogens.

In consideration of the plasticity problem, slip lines displaying strike-slip motion form when a rigid indentor converges upon a semi-infinite plastic body. These slip lines, acting as escape structures, respond to the imposed strain by allowing material in the semi-infinite plastic body to move away from the rigid indentor. Molnar and Tapponier (1984) believe that such escape structures account for much of the deformation north of the Himalayas. Applying this to the Wopmay and Trans-Hudson Orogens, we believe that the Great Lake Shear Zone, the Needle Falls Shear Zone, and the VRSZ may represent similar escape structures. Using the plasticity problem analogy, we believe that the Superior and/or Slave Cratons may have acted as rigid indentors converging upon the semi-plastic Trans-Hudson Orogen. The resulting slip geometry and the relative positions of these faults to the orogen should produce dextral strike-slip movement along these faults. Recent fieldwork in the VRSZ (Carolan and Collerson, 1988) , the Needle Falls Shear Zone (Stauffer and Lewry, 1988) and the Great Slave Lake Shear Zone (Hamner, 1980) indicates that relative motion along these faults is indeed strike-slip and dextral. Thus, recent evidence suggests that the tectonic juxtaposition of the Rae and Hearne Cratons occurred in response to intracratonic transcurrent movement rather than to continental collision.

Offset dykes that yield Rb-Sr model ages of 1910 Ma, as well as cross-cutting relationships between the ca. 1820 Ma (Bickford *et al.*,1986) Junction Granite and the VRSZ provide loose constraints indicating that both the Slave and Superior Cratons may have played roles in the movement history of the VRSZ. Kinematic data are consistent with the interpretation of the shear zone as an intracratonic transcurrent fault, possibly related to collisional indentation of either or both the Slave Craton to the northwest or the Superior Craton to the southeast. The VRSZ may also be an older Archean feature, such as an early rift, that was reactivated during Early Proterozoic continental collision. Further geochronologic work in progress by the authors will, it is hoped, further constrain the timing of fault movement and the relative roles of the Slave and Superior Cratons in the formation of the VRSZ.

7. Sampling

Samples of the metasediments and volcanics from the VRSG, orthogneisses from low shear enclaves, and felsic gneisses from the Virgin River Domain have been collected for U-Pb geochronology. Such information will be used to determine the relationship of the metasediments to the surrounding quartzofeldspathic gneiss. The metabasalt and gabbros from low shear domains have been sampled for Sm-Nd geochronology. Offset granitic dykes have been sampled for Rb-Sr analysis. This information will be necessary in constraining the movement history of the VRSZ.

8. Summary

1) The area exhibits a well exposed section across the VRSZ, an approximately 4 km-wide zone of mylonitic rocks which separates the high grade Archean rocks

of the Western Granulite Domain from lower amphibolite facies rocks of the Virgin River Domain.

2) The VRSZ is characterized by a complex intercalation of low shear enclaves within the main mylonitic body.
3) At least four episodes of folding affected the VRSZ and the Virgin River Domain.
4) Observed stretching lineations plunge to the northeast at 5° to 45°, averaging approximately 20°. This plunge indicates that the major component of fault movement was strike-slip with a slight east-side-up component.
5) Kinematic indicators, including rolling structures, asymmetric pinch-and-swell structures, C-S structures, asymmetric folds, and offset granitic dykes indicate the strike-slip motion was dextral.
6) Relict pillow structures preserved in outcrop-scale low shear domains suggest the possibility of an early rift sequence in the area.
7) The movement history of the VRSZ during the Early Proterozoic may be modelled using the plasticity problem of plane indentation. That the VRSZ was an Archean discontinuity reactivated by Early Proterozoic thermotectonism has not yet been resolved.

9. Acknowledgements

We are grateful to Saskatchewan Energy and Mines for financial support of fieldwork. We appreciate J.F. Lewry for his invaluable aid in expediting fieldwork and providing guidance in the field. Excellent field assistance was provided by Alden Hough. This research was also supported by a National Science Foundation Grant (EAR 87-20442) to Collerson and Bickford.

10. References

Bickford, M.E., Van Schmus, W.R., Macdonald, R., Lewry, J.F. and Pearson,J.G. (1986): U-Pb geochronology project for the Trans-Hudson Orogen: current sampling and recent results; *in* Summary of Investigations 1986, Sask. Geol. Surv., Misc. Rep. 86-4, p101-107.

Carolan, J. and Collerson, K.D. (1988): The Virgin River Shear Zone in the Careen Lake Area: field relationships and kinematic indicators; *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p92-96.

Gilboy, C.F. (1980): Reconnaissance bedrock geology: Chambeuil Lake east area (part of NTS area 74P); *in* Summary of Investigations 1980, Sask. Geol. Surv., Misc. Rep. 80-4, p14-16.

Hamner, S. (1986): Asymmetric pull aparts and foliation fish as kinematic indicators; J. Struct. Geol., v8, no2, p111-122.

Hoffman, P.F. (1988): United Plates of America, the birth of a craton: Early Proterozoic assembly and growth of Laurentia; Annu. Rev. Earth Planet. Sci., v16, p543-603.

Johnson, R.L. (1968): The geology of the Nyberg Lakes Area (west half), Saskatchewan; Sask. Dep. Miner. Resour., Rep. 118, 15p.

Lewry, J.F. (1974): Structural relationships in the La Loche (north) map sheet and adjacent areas: *in* Summary Report of Field Investigations 1974, Sask. Geol. Surv., p46-55.

Lewry, J.F. and Sibbald, T.I.I. (1977): Variation in lithology and tectonomorphic relationships in the Precambrian basement of northern Saskatchewan; Can. J. Earth Sci., v14, p1453-1467.

Macdonald, R. (1980): New edition of the geological map of Saskatchewan, Precambrian Shield area; *in* Summary of Investigations 1980, Sask. Geol. Surv., Misc. Rep. 80-4, p19-21.

Sibbald, T.I.I. (1973): 74-B-NW: Mudjatik (NW); *in* Summary Report of Geological Investigations Conducted in the Precambrian Area of Saskatchewan, 1973, Sask. Dep. Miner. Resour., p35-42.

Stauffer, M.P. and Lewry, J.F. (1988): Kinematic investigation of part of the Needle Falls Shear Zone; *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p156-160.

Tella, S. and Eade, K.E. (1986): Occurrence and possible tectonic significance of granulite fragments in the Tulemalu Fault Zone, District of Keewatin, N.W.T., Canada; Can. J. Earth. Sci., v23, p1950-1962.

Van Den Dreissche, J. and Brun, J.-P. (1987): Rolling structures at large shear strain; J. Struct. Geol., v9, no5/6, p 691-704.

Wallis, R.H. (1970): The geology of the Dufferin lakes (west half), Saskatchewan; Sask. Dep. Miner. Resour., Rep. 132, 59p.

Structural Relationships of the Western Granulite Domain and the Virgin River Shear Zone

James Carolan[1], Charles H. Crocker[1] and Kenneth D. Collerson[1]

Carolan, J., Crocker, C.M. and Collerson, K.D. (1989): Structural relationships of the Western Granulite Domain and the Virgin River Shear Zone; *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

This report documents field relations on islands in east Careen Lake in a 4.5 km-wide transect that links areas being studied by Crocker and Carolan (Figure 1). Rocks in the area comprise gneisses of the Western Granulite Domain that show progressive effects of ductile deformation associated with the Virgin River Shear Zone (VRSZ). This Early Proterozoic transcurrent fault is a prominent northeast-trending 4 km-wide zone of mylonitic rocks and elongate low deformation enclaves (Carolan and Collerson, 1988, and this volume). Rocks in the shear zone are derived mainly from the Western Granulite Domain and less so from the Virgin River Domain, and include several generations of heterogeneous felsic and mafic gneiss, augen gneiss, and a mixed assemblage of supracrustal rock types (Figure 2), similar to those in the west Careen Lake map area where a detailed lithostructural history has been established by Crocker and Collerson (1988). The purpose of this extended study was to document the structural and textural modification of gneisses in the Western Granulite Domain as they are progressively involved in the shear zone.

1. Brief Rock Descriptions

a) Heterogeneous felsic and mafic gneiss

Compositely layered tonalitic, granitic and gabbroic gneisses are correlated with similar rock types in the West Careen Lake map area. The rocks show macroscopic to microscopic structures that are progressively flattened as the shear zone is approached. In contrast to the pervasive blue quartz reported in gneisses to the west, gneisses in close proximity to the shear zone exhibit clear quartz.

b) Augen Gneiss

Discrete mappable layers of augen gneiss up to 500 m wide, which occur on a number of islands in the transect area, are medium to coarse grained and contain variably flattened augen of potassium feldspar that provide a good indicator of strain intensity. The augen gneisses, which are correlated with minor megacrystic granites observed elsewhere in the Careen Lake region, are apparently more abundant on the islands in Careen Lake than the area to the northwest.

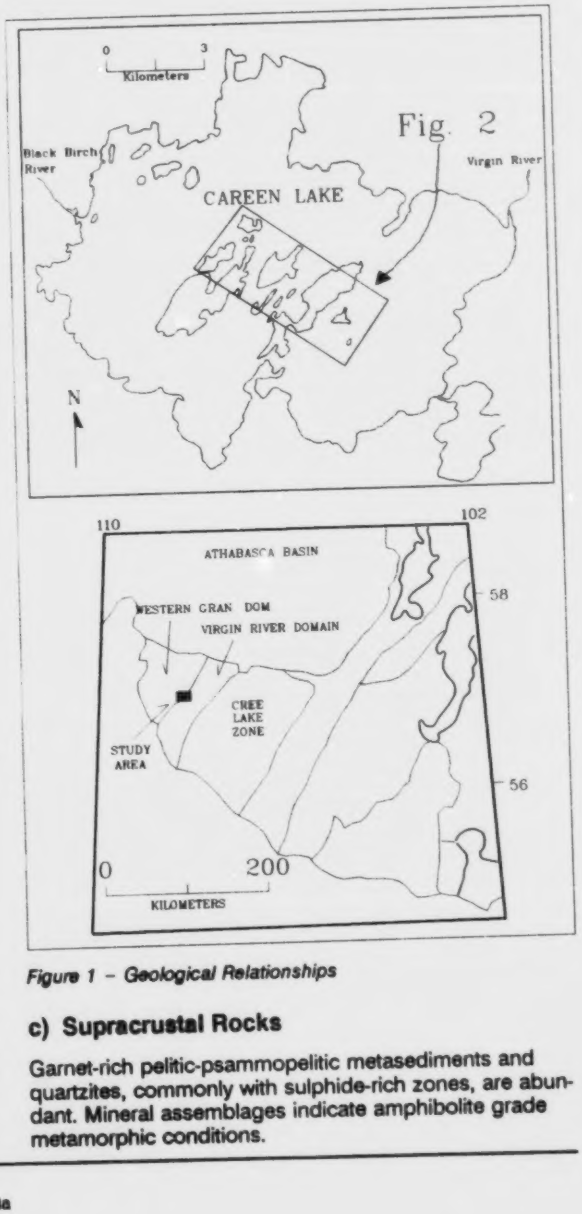


Figure 1 - Geological Relationships

c) Supracrustal Rocks

Garnet-rich pelitic-psammopelitic metasediments and quartzites, commonly with sulphide-rich zones, are abundant. Mineral assemblages indicate amphibolite grade metamorphic conditions.

---

[1] Earth Sciences Board, University of California, Santa Cruz, California

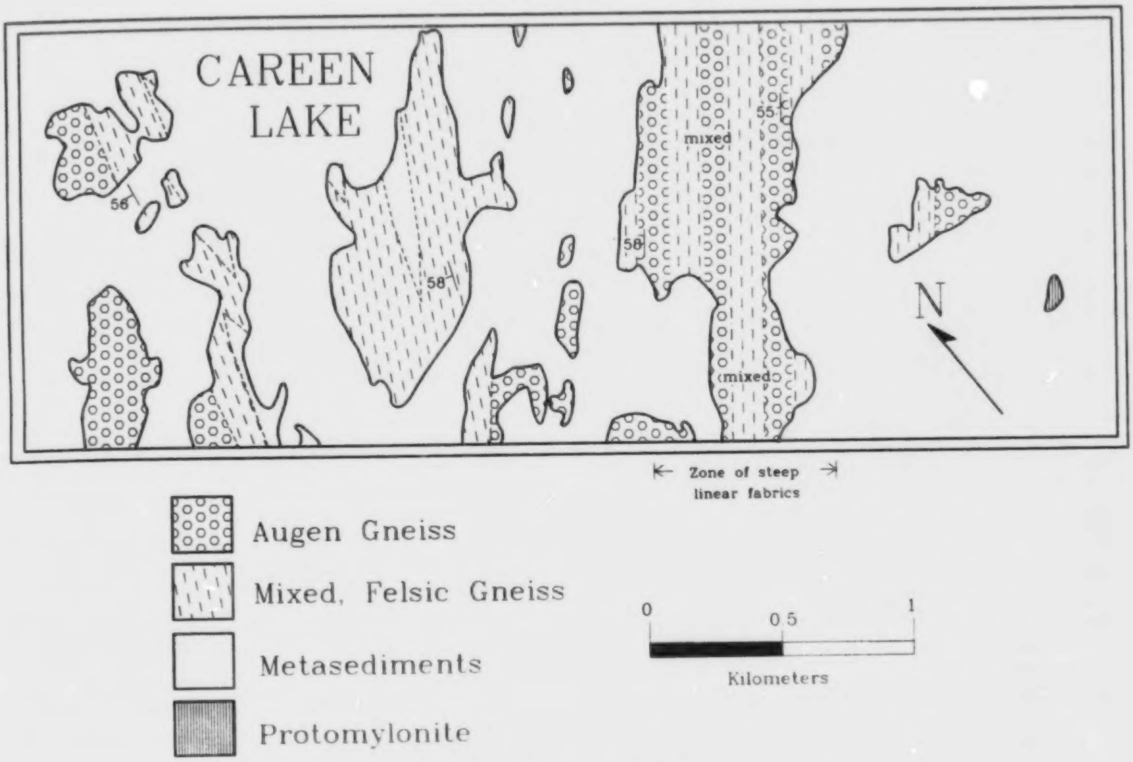


Figure 2 - Geological relationships along the transect.

d) Protomylonite

Protomylonitic rock exposed along the western margin of the shear zone is derived from gneisses of the Western Granulite Domain. Grain morphologies within the protomylonite indicate that these rocks experienced a significant component of pure shear as well as simple shear.

2. Structural Geology

An outline of the interpreted regional structural sequence is given in Carolan and Collerson (this vol.) and is not fully repeated here. Gneisses in the Western Granulite Domain are dominated by a strong composite layering that is believed to be the result of transposition associated with inhomogeneous D2 and D3 strain. These gneisses also contain a pervasive L3 intersection lineation defined by elongated quartz lenticles and aligned mafic grains that parallel the axes of F3 folds which plunge at about 15° north-northeast. At about 2.5 to 3.0 km from the shear zone these fabric elements are progressively flattened and rotated into parallelism with structures in the zone (Figure 3). F2 and F3 folds become more isoclinal and eventually so much flattened that fold hinges are no longer discernable. Close to the fault zone the intersection lineation is completely obliterated as it rotates into the plane of flattening. As

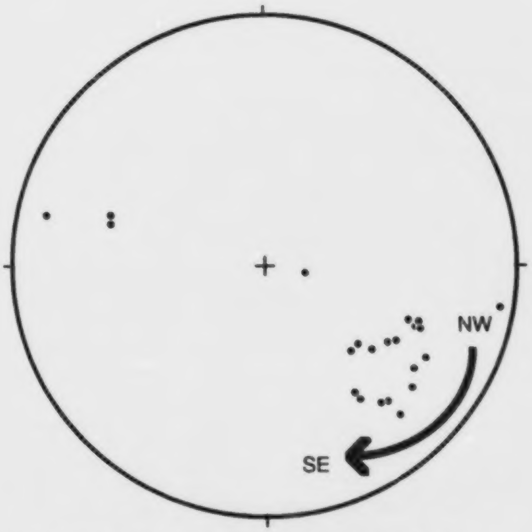


Figure 3 - Poles to layering plotted on an equal-area stereonet displaying progressive rotation of gneissic layering into the shear zones. Arrow moves from northwest to southeast.

the amount of flattening increases still further (within 1 to 2 km of the shear zone) a new L-S fabric is developed.

Between flattened gneisses that preserve lithological characteristics of the Western Granulite Domain and the eastern mylonitic margin of the VRSZ is a 600 m-wide unit of gneiss with a lineation which plunges at 50° to the northwest. No transition between the shallow L-S fabrics to the west could be recognized in the study area.

Protomylonite exposed along the margin of the shear zone exhibits no obvious linear elements. The contact between the protomylonite and the flattened gneisses is not exposed in the study area.

3. Interpretation

Nearly all features observed in the shear zone can be explained by a simple rotation of regional fabric into a dextral strike-slip ductile fault. Recent fieldwork in the VRSZ (Carolan and Collerson, this volume) indicates that motion in the main mylonite body was strike-slip and dextral. A previous compilation of aeromagnetic features by Lewry and Sibbald (1980) shows a similar deflection into the shear zone and appears to support the present kinematic model.

The steeply-dipping vertical lineations observed in areas of extreme flattening do not seem to be the result of simple rotation. In this zone, any lineation present would be expected to closely parallel the stretching lineation of the main shear zone. The fact that these lineations do not indicates either 1) that the shear zone was not a dextral strike-slip fault during the most recent Early Proterozoic activity as interpreted by Carolan and Collerson (1988), or 2) that these lineations are relicts of an earlier event. The lineations may also be the result of a progressive rotation by more recent movement along the shear of an earlier developed fabric into the shear zone which may have originally been at a different (possibly shallower) orientation. However, observations within the main sequence of mylonites indicate that motion was dextral and strike-slip. The VRSZ may therefore represent an earlier, possibly Archean structure (with an unconstrained early movement history) that was reactivated during the Early Proterozoic. Kinematic indicators that suggest dextral strike-slip motion may be features that developed during the most recent movement along the VRSZ .

4. Acknowledgements

We are grateful to Saskatchewan Energy and Mines for financial support and providing logistics for fieldwork. We thank John F. Lewry for his invaluable assistance. This research was also supported by National Science Foundation Grant (EAR 87-20442) to Collerson and Bickford.

5. References

Carolan, J. and Collerson, K.D. (1988): The Virgin River Shear Zone in the Careen Lake Area: field relationships and kinematic indicators; *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p92-96.

Crocker, C.H. and Collerson, K.D. (1988): Archean and Early Proterozoic field relationships in the Careen Lake Area of the Western Granulite Domain; *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p97-102.

Lewry, J.F. and Sibbald, T.I.I. (1980): Thermotectonic evolution of the Churchill Province in northern Saskatchewan; Tectonophysics, v68, p45-82.

Geology of Early Proterozoic Gneissic Rocks, Black Birch Lake Area: Progress Report 2

S. E. Orrell[1] *and M. E. Bickford*[1]

Orrell, S.E. and Bickford, M.E. (1989): Geology of Early Proterozoic gneissic rocks, Black Birch Lake area: Progress Report 2; *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

Mapping of Precambrian rock exposures in the Black Birch Lake area, which began in the summer of 1988 (Orrell *et al.*, 1988), was completed in the summer of 1989. The goal of this study is to combine field mapping with geochemical studies in order to determine the crustal evolution of the Mudjatik Domain in the Cree Lake Zone.

The purpose of this paper is to document the later field work, and to summarize the progress of the study, including preliminary chemical and petrographic work. Approximately 150 km^2 in the Black Birch Lake area was mapped at 1:20,000 scale. The area was previously mapped at reconnaissance-scale (1:100,000) by Sibbald (1973). The area is heavily wooded and locally swampy. Maximum relief is about 60 m. Float-equipped aircraft from Buffalo Narrows, 120 km southwest of Black Birch Lake, afforded access.

1. General Geology

The Cree Lake Zone is an ensialic portion of the Trans-Hudson Orogen. Accreted arcs of the Reindeer Zone (Lewry *et al.*, in press) lie to the east and south, and the Rae Craton lies to the west. Field evidence, including rock types, metamorphic grade and structural style, led previous workers to interpret the Cree Lake Zone as an Archean continental platform with a veneer of early Proterozoic sediments, all variably remobilized during Hudsonian collisional orogenesis (Lewry and Sibbald, 1977, 1980).

The current study area lies in the Mudjatik Domain of the Cree Lake Zone, a domain dominated by granites (with associated granite pegmatites) and felsic (tonalitic to granitic) gneisses. These are accompanied by some metasedimentary rocks, including those of mafic, quartzitic, quartzofeldspathic, pelitic and carbonaceous bulk compositions. The structural style is non-linear; outcrop patterns commonly define dome-and-basin fold interference structures (Harper, 1988a, 1988b; Orrell *et al.*, 1988).

2. Lithologic Units and Rock Descriptions

Basement units in the Black Birch Lake area include tonalitic gneisses and granitic augen gneiss which occur as mantles of the major antiforms. Metasedimentary units are predominately quartzitic with interlayered pelites, psammites, quartzofeldspathic rocks, and mafites. Iron formation and carbonates present elsewhere in the Mudjatik domain, as for example in the adjacent Ithingo Lake area (Harper, 1988a) have not been found in the Black Birch Lake area. Relatively undeformed biotite leucogranite intrudes both the basement and metasedimentary sequences, occurring as lenses and sheets oriented parallel or subparallel to compositional layering in the area.

a) Tonalitic Gneiss

The tonalitic gneiss, the oldest unit exposed, is white or grey on fresh surfaces. On the limbs of the major fold structures, the tonalitic gneiss is typically strongly layered at centimetre- to metre-scales, alternating from dark grey or black mafic to ultramafic layers, to white or pale grey quartz-plagioclase layers. Areas of lower strain can be found in the hinges of the major structures, as for example on the north hinge of the east Cabanel Bay antiform (Figure 1). In these zones, it is clear that the rock is composed of a number of discrete lithologic units, including older tonalitic gneisses, granitic dikes, and mafic and ultramafic (pyroxenite, hornblendite) blocks and layers.

b) Augen Gneiss

The augen gneiss is exposed as a single layer in the tonalitic gneiss, and is distinguished by its pink color and feldspar megacrysts. The potassium feldspar megacrysts are typically larger and less abundant than white plagioclase megacrysts. Layering is best defined by thin centimetre-wide pink fine- to medium-grained leucogranite layers, which are parallel or subparallel to long axes of the feldspar megacrysts. The augen gneiss is thought to represent a megacrystic granite which intruded the tonalitic rocks prior to Hudsonian orogenesis. Intrusive relations between the augen and tonalitic gneisses were observed in the adjacent Ithingo Lake area by Harper (1988a).

c) Quartzite

Quartzite comprises about 50 percent of the metasedimentary rocks in the area. The most common variety is blue grey and pink layered; the blue grey layers are pure or nearly pure medium- to coarse-grained quartz, whereas the thinner pink layers are com-

---

(1) The University of Kansas, Lawrence, Kansas 66045

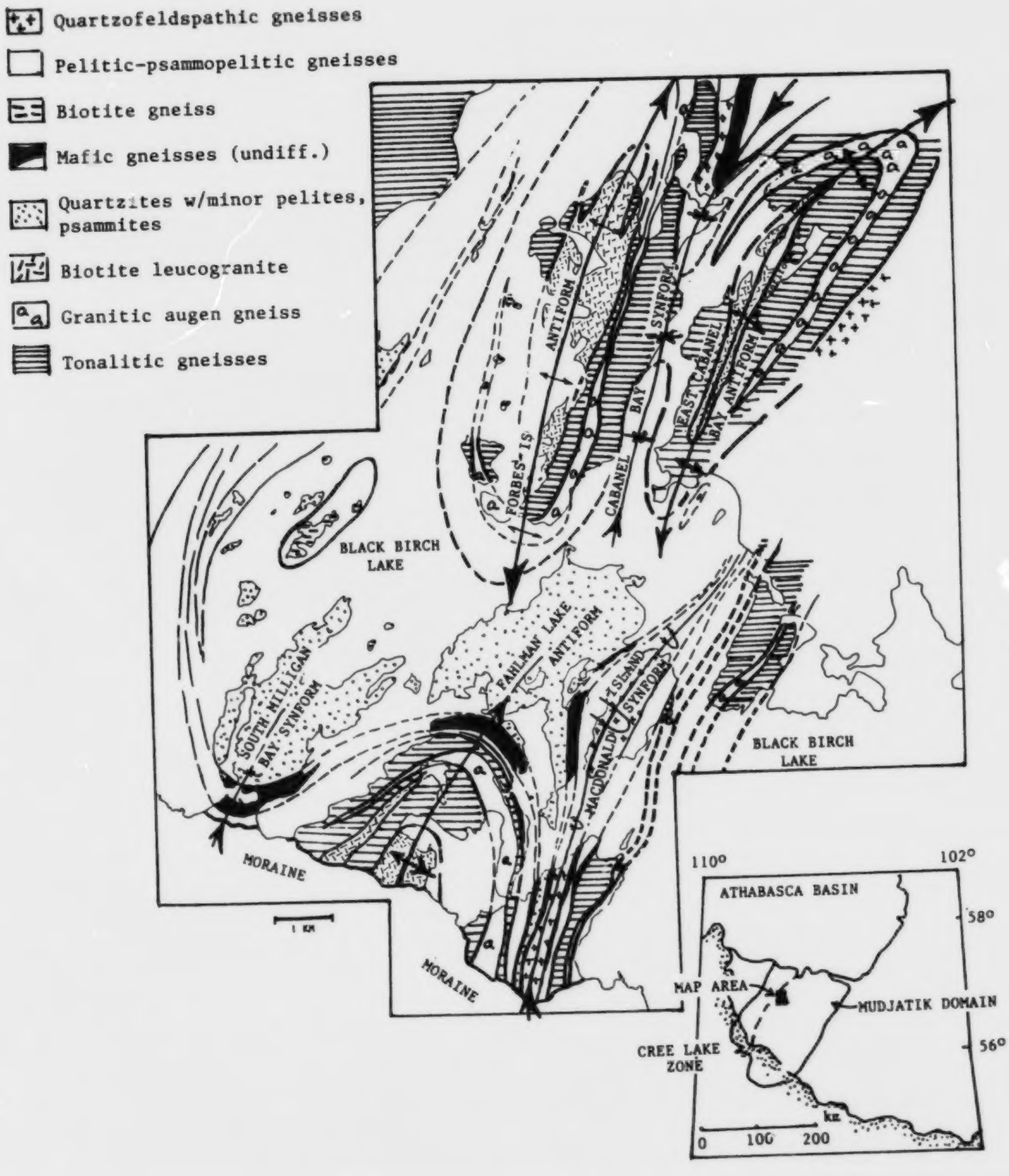

Quartzofeldspathic gneisses
Pelitic-psammopelitic gneisses
Biotite gneiss
Mafic gneisses (undiff.)
Quartzites w/minor pelites, psammites
Biotite leucogranite
Granitic augen gneiss
Tonalitic gneisses
FORBES IS. ANTIFORM
CABANEL BAY SYNFORM
EAST CABANEL BAY ANTIFORM
BLACK BIRCH LAKE
FAHLMAN LAKE ANTIFORM
MACDONALD ISLAND SYNFORM
SOUTH MILLIGAN BAY SYNFORM
BLACK BIRCH LAKE
MORAINE
MORAINE
1 KM
110°
102°
ATHABASCA BASIN
58°
MAP AREA
MUDJATIK DOMAIN
56°
CREE LAKE ZONE
km
0
100
200

Figure 1 - Sketch map showing major structures and rock types in the Black Birch Lake area, Mudjatik Domain.

prised of fine- to medium-grained pelitic or psammopelitic material. Dark biotitic layers and white sillimanitic layers are also present. Foliation in these quartzites tends to be swirly and nebulous. A rarer variety of quartzite is white, medium grained and very homogeneous, with only centimetre-thick layers of mafic material composed of andraditic garnet (Table 1, sample 88-251), epidote, clinopyroxene and (late) actinolite in one notable instance.

Table 1 – Selected Chemical Analyses of Garnet in Metasedimentary Rocks.

Sample No.	88-193 core	88-193 rim	88-145 rim	88-145 core	88-145 interior	88-188	88-48a	88-251
SiO2	38.15	37.80	38.35	37.81	38.41	37.38	38.08	37.69
Al2O3	20.96	21.37	21.82	21.29	21.64	21.29	22.38	9.28
TiO2	0.01	0.00	0.01	0.02	0.02	0.00	0.05	0.40
FeO*	28.53	31.44	33.19	30.47	31.92	33.00	29.59	3.03
Fe2O3								19.08
MnO	9.35	4.12	0.95	0.95	0.78	0.68	1.29	1.95
MgO	2.02	4.58	3.21	3.83	5.20	1.70	6.11	0.38
CaO	2.18	2.03	5.13	5.67	3.85	7.16	3.56	30.48
Na2O	0.03	0.00	0.02	0.17	0.01	0.00	0.02	0.00
K2O	0.05	0.07	0.04	0.05	0.04	0.00	0.15	0.06
Total:	101.28	101.39	102.72	100.26	101.67	101.21	101.23	102.35
Cations per 12 oxygens								
Si	3.04	2.98	2.98	2.99	2.99	2.97	2.95	3.30
Al	1.97	1.99	2.00	1.99	1.99	2.00	2.05	0.96
Ti	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Fe	1.90	2.07	2.16	2.02	2.08	2.20	1.92	0.22
Fe3+								0.42
Mn	0.63	0.28	0.06	0.06	0.05	0.05	0.08	0.14
Mg	0.24	0.54	0.37	0.45	0.60	0.20	0.71	0.05
Ca	0.19	0.17	0.43	0.48	0.30	0.61	0.30	2.86
Na	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
K	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.01
Total:	7.98	8.03	8.02	8.03	8.02	8.03	8.03	7.99

* In sample 88-251, 15 percent Fe as Fe2+:
in all other samples all Fe as Fe2+

88-193	Metapelite
88-145	Metapelite
88-188	Metawacke
88-48A	Metatuff
88-251	Quartzite

d) Mafite

Three distinct types of mafite are recognized in the area, all in relatively low abundance: 1) the structurally highest is considered to be metavolcanic, based on its intimately interlayered metarkoses, internal variability and textures; 2) the next lower mafite is probably a metatuff, although conclusive textural evidence is lacking and 3) the structurally lowest mafite is a fine-grained internally homogeneous and featureless amphibolite.

Metavolcanic rock is composed primarily of hornblende amphibolites, which are characterized by abundant small (1 to 15 mm wide) rootless isoclinally-folded quartz stringers. Subordinate rock types include calc-silicates (diopside + plagioclase) and hornblendite.

Metatuffs are dark grey amphibolites that are interlayered with garnet-bearing amphibolite and rare thin discontinuous hornblendite. Amphiboles are typically composed of anthophyllite-gedrite and cummingtonite (Table 2, sample 88-48a). Garnets are almanditic and display remarkably little zoning (Table 1, sample 48a). Plagioclase is very calcic (An89). Peraluminous layers and dykes composed of garnet, cordierite, biotite, sillimanite, monazite, and in places hercynitic spinel occur together with this unit, and may represent anatectic melts derived from it.

Amphibolite, the lowest mafite unit is very dark grey, fine- to medium-grained and typically finely layered. No relict textures or structures were observed within it. Concordant metre-wide rusty sillimanitic layers are associated with it.

e) Biotite Gneiss

Biotite gneiss is dark blue grey, medium grained and homogeneous. Foliation is defined by parallel alignment of biotite grains. There is only one exposure on an island in the southwestern bay, and no contacts were observed. Associated rock types include minor muscovite porphyroblastic gneiss and friable, variegated rusty weathering, fine-grained quartzofeldspathic gneiss. Outcrops of biotite gneiss appear to be surrounded by outcrops of metasedimentary rocks. The unit may be derived from a diorite, or more likely a wacke.

f) Psammitic Gneisses

Psammitic gneisses are pink, well-layered quartzofeldspathic rocks, distinguished from other quartzofeldspathic gneisses by their layering and by the common occurrence of garnet and cordierite megablasts in leucosomes. Garnet in these leucosomes typically occurs as spherical intergrowths (4-5 cm diameter) with quartz. While both cordierite and garnet are locally abundant in leucosomes, equilibrium textures between the two minerals are lacking. A single garnet lead analysis has been made; the Pb-Pb age of this fraction is about 2240 Ma, suggesting either an older detrital component or an older metamorphic event.

g) Pelitic Gneiss

Pelitic rocks are typically coarse grained and dark bluish grey, with abundant red garnets larger than one cen-

Table 2 – Selected Chemical Analyses of Amphiboles in Metasediments and Mafic Enclaves.

Sample No.	88-48a i.	88-48a ii.	88-48a iii.	88-188	88-145 i.	88-145 ii.	88-217 i.	88-217 ii.
SiO2	52.86	51.26	47.57	41.12	52.17	52.71	46.23	46.18
Al2O3	1.91	4.65	6.76	11.78	1.14	2.05	10.22	9.85
TiO2	0.16	0.23	0.15	1.44	0.15	0.16	1.19	1.15
FeO*	24.86	21.44	23.08	23.97	27.69	27.16	18.07	17.79
MnO	0.38	0.35	0.29	0.09	0.19	0.18	0.31	0.33
MgO	16.19	17.83	17.49	5.93	14.92	14.55	11.28	11.23
CaO	1.36	0.64	0.68	11.38	0.66	1.39	12.53	12.59
Na2O	0.27	0.56	0.59	0.79	0.10	0.11	1.11	1.16
K2O	0.10	0.08	0.11	1.42	0.05	0.07	0.92	0.87
Total:	98.09	97.04	96.72	97.92	97.07	98.38	101.86	101.15
Cations per 24 oxygens								
Si	7.78	7.50	7.09	6.39	8.19	8.14	6.95	6.99
Al	0.33	0.80	1.19	2.16	0.21	0.37	1.81	1.76
Ti	0.02	0.03	0.02	0.17	0.02	0.02	0.13	0.13
Fe	3.06	2.62	2.88	3.11	3.63	3.51	2.27	2.25
Mn	0.05	0.04	0.04	0.01	0.03	0.02	0.04	0.04
Mg	3.55	3.89	3.89	1.37	3.49	3.35	2.53	2.53
Ca	0.21	0.10	0.11	1.89	0.11	0.23	2.02	2.04
Na	0.08	0.16	0.17	0.24	0.03	0.03	0.32	0.34
K	0.02	0.01	0.02	0.28	0.01	0.01	0.18	0.17
Total:	15.09	15.16	15.39	15.63	15.71	15.68	16.26	16.26

* All Fe as Fe2+

88-48A	Metatuff
88-188	Metapelite
88-145	Metapelite
88-217	Mafic enclave in quartzofeldspathic gneiss

timetre diameter, and blue cordierite grains. The garnets are almanditic (Table 1, sample 88-193 and 88-145) and zoned from lower manganese in the cores to higher at the rim, a pattern which is commonly considered to represent retrogressive diffusion. Biotite and sillimanite are also abundant in these rocks, which are interpreted as derived from shales.

h) Quartzofeldspathic Gneisses

Quartzofeldspathic gneisses are typically pale pink, grey or white and medium to coarse grained. Both potassium feldspar and plagioclase are present. Biotite is the only common mafic mineral, as garnet and hornblende are absent. The quartzofeldspathic gneisses range in texture in a single outcrop from foliated and well-layered to granoblastic and nearly massive. Zones of mafic enclaves are locally abundant in the southern part of the area, but are absent in the north. Mafic enclaves are commonly composed of hornblende amphibolite (Table 2, sample 88-217). The quartzofeldspathic gneisses may be derived from felsic volcanic, arkosic, and/or granitic protoliths, and the zones of mafic enclaves may have originated as dismembered dikes.

i) Leucogranite

The leucogranite is a pink, fine- to medium-grained rock that is locally incipiently foliated with the parallel alignment of biotite grains. The unit occurs in thin metre to ten metre wide subconcordant to concordant bodies on the limbs of the major structures. It also occurs in extensive bodies in the cores of the same structures, where it exhibits a texture which varies continuously from fine grained to pegmatitic, apparently reflecting local concentrations of igneous fluids. Additionally these larger bodies of leucogranite locally contain metre-size and larger inclusions of tonalitic and augen gneiss. Foliation in these bodies is typically parallel to that in the nearest outcrop of tonalitic gneiss. The leucogranite is thought to have been emplaced penecontemporaneously with the folding that produced the dome-and-basin interference pattern, based on parallelism of its contacts to that generation of structures.

j) Granite Pegmatite

Discordant granite pegmatites which comprise much less than one percent of the area, are biotitic and contain aligned blocks of the local country rock, which is typically metasedimentary. Garnet and monazite are present in very low abundances, indicating perhaps a mildly peraluminous composition. The margins of these pegmatites are not markedly finer-grained than the interiors, suggesting that the country rocks were still at relatively high temperatures at the time of dike emplacement.

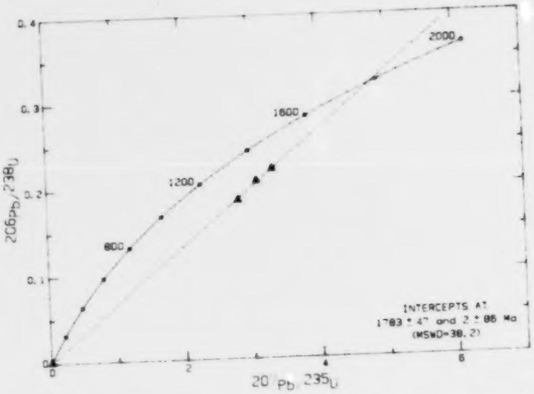


Figure 2 – Preliminary zircon U-Pb determination. Note regression is forced through 2 Ma.

A preliminary age estimate of 1783 ± 47 Ma is assigned to one of these pegmatite bodies, based on the U-Pb systematics of three fractions of zircon (Figure 2), with a forced lower intercept of about 0 Ma. This age is interpreted as a crystallization age for the pegmatite, and a constraint on the end of deformation. Analysis of additional fractions of zircon, garnet, and monazite is currently in progress.

3. Structure

a) Foliation

The regional tectonic foliation defined by lithologic contacts and mineral foliations predates all folding, and defines all folds. On the other hand, much of the outcrop scale compositional layering resulted either from syntectonic migmatization in the early stages of the orogenic cycle, or from inhomogeneous deformation, probably during later (D3) stages of folding, or both.

b) Lineation

Lineation is found relatively rarely, and is restricted to the common limb between the Fahlman Lake antiform and the Macdonald Island synform, where mineral lineations are defined by the parallel alignment of hornblende grains, or by elongate streaks of medium-grained biotite. The lineations plunge moderately to the east and southeast.

c) Folds

The earliest formed (D1) folds are mesoscopic isoclinal folds with axial planes lying parallel to foliation. As with mineral lineations, these are only abundant on the common limb between the Fahlman Lake antiform and the Macdonald Island synform. The Macdonald Island synform is a tight overturned structure thought to represent one of the early megascopic recumbent folds interpreted by Lewry and Sibbald (1977) which has been refolded into its current orientation by later stages of deformation.

Probable second generation (D2) folds have also been observed only at outcrop scale. These rare structures are open and asymmetric, with northwest-striking and steep northeast-dipping axial planes.

Outcrop patterns and foliations in the tonalitic and augen gneisses define three asymmetric doubly-plunging antiforms; the Fahlman Lake antiform, the Forbes Island antiform, and the east Cabanel Bay antiform (Figure 1). All three of these antiforms and intervening synforms are interpreted as D3 deformation structures. Basement rocks are exposed only in the cores of these antiforms, where they comprise medium to coarse-grained or pegmatitic leucogranite mantled by tonalitic gneisses enclosing what is apparently a single sheet of augen gneiss. The west limbs of the Forbes Island and Fahlman Lake antiforms are very steep to vertical, whereas the east limbs dip only moderately. In contrast, the east Cabanel Bay antiform is nearly symmetrical, with moderate dips on both limbs. These antiforms are separated by synforms (the Cabanel Bay Synform and the South Milligan Bay synform) which are defined by outcrop pattern and foliation mainly in psammitic or quartzofeldspathic gneiss.

4. Metamorphism

The presence of deformed garnets which are apparently flattened in the plane of foliation suggests that relatively high temperatures prevailed early in the deformational cycle. There is also evidence of post-tectonic garnet growth, suggesting that the thermal event outlasted tectonism. The absence of zoning in many garnets may indicate that cooling, possibly engendered by rapid uplift, was rapid enough to prevent diffusion.

Preliminary thermobarometric determinations using garnet-biotite and garnet-amphibole thermometry and garnet-plagioclase-sillimanite-quartz barometry suggest peak metamorphic conditions of at least 650° C at a maximum of 3 kilobars pressure. Relict green hercynitic spinels occurring in quartz-bearing peraluminous dykes associated with the metatuffs, may indicate that temperatures in excess of 700° C were reached.

5. Acknowledgements

The guidance of Drs. J. F. Lewry, K. C. Collerson and R. Macdonald is gratefully acknowledged. Microprobe analyses were made possible by a grant from the Sigma Xi Foundation and the kindness of Bob Jones of UCLA. Field support was provided by Saskatchewan Energy and Mines. Financial support was also provided by the U. S. National Science Foundation (grant #EAR-8719997).

6. References

Harper, C.T. (1988a): Mudjatik domain, geology and gold studies: Ithingo Lake; *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p42-48.

________ (1988b): Mudjatik domain, geology and gold studies: Porter Lake Area; *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p49-53.

Lewry, J.F. and Sibbald, T.I.I. (1977): Variation in lithology and tectonometamorphic relationships in the Precambrian basement of northern Saskatchewan; Can. J. Earth Sci., v14, p1453-1467.

________ (1980): Thermotectonic evolutions of the Churchill Province in northern Saskatchewan; Tectonophysics, v68, p45-82.

Lewry, J.F., Thomas, D.J., Macdonald, R.J. and Chiarenzelli, J. (in press): Structural relations in accreted terranes of the Trans-Hudson orogen, Saskatchewan: Telescoping in a collisional regime?; *in* Lewry, J. F. and Stauffer, M.R. (eds.), The Early Proterozoic Trans-Hudson Orogen of North America; Geol. Assoc. Can., Spec. Pap.

Orrell, S.E., Tangeman, J.A. and Bickford, M.E. (1988): Geology of Early Proterozoic gneissic rocks, Black Birch Lake area; *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p84-91.

Sibbald, T.I.I. (1973): 74-B-NW: Mudjatik (NW); in Summary Report of Geological Investigations Conducted in the Precambrian Area of Saskatchewan 1973; Sask. Dept. Miner. Resour., p35-42.

Mineralized Core Collection

A. J. Gracie

Gracie, A.J. (1989): Mineralized core collection; *in* **Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.**

The Mineralized Core Collection has been previously described (Gracie, 1984, 1985, 1986, 1987, 1988) and an index to the collection was released in 1987 as a data file (Gracie *et al.*, 1987) and an update completed this summer. The index identifies the location of all core by longitude and latitude and on 1:250,000 scale maps, and gives full particulars of each hole: company, mineral dispositions, exploration commodity, year, hole number, core size, hole bearing and inclination, length of sample, reference to other exploration data and storage location.

The mineralized core is housed in the Precambrian Geological Laboratory in La Ronge. Contributions to the Mineralized Core Collection totalled some 1365 m in 1989 (Table 1) and were made up of cores from mineral

Table 1 - Mineralized Core Acquisitions (September 1, 1988 to August, 1989)

Company or Joint Venture Operator	*Commodity*	*NTS Area*	*No. of Holes*	*Core Size*	*Property/Deposit Location by Lake*	*Length (m)*
Amok Ltd./ Cluff Mining	U	74-K-5	Parts	BQ	Dominique Peter Mine Cluff Lake	84.58
Cameco Skeleton Log Only Not Included in Total	U	74-F-11	Small Parts 16	BQ	MPP 1076 Derkson Lake	(1051.02) (in nine 6 m boxes)
	Au	63-L-9	1	NQ	CBS 3102 Laurel Lake	60.25
	Au	63-L-16	1	NQ	S102861 Graham Mine	149.1
	Au	73-P-16	1	NQ	ML 5118 Star Lake	103.3
	PGE + Au	74-N-B	1 Incomplete Hole	BQ	ML 4762 Nicholson #2 Nicholson Bay	22.3
Eldor Resources Ltd.	PGE + Au	74-N-B	1	BQ	S103239 Nicholson #3 Nicholson Bay	97
Esso Minerals Canada	(Zn, Pb)	64-E-5+12	2	NQ	CBS 8084 Brakewell Lake	254.7
Granges Exploration Ltd.	(Cu, Zn)	63-L-10	1 (16.8 m missing)	NQ, BQ	MPP 1138 McDermott Lake	71.8
	(Cu, Zn)	63-L-11	1 Phanerozoic missing	BQ	CBS 7097 Bigstone Lake	184.1
	Au	63-L-16	1	AQ	CBS 3084 Wolverine Lake	69.2
Greater Lenora Resource Corp.	Au	74-N-7	1	BQ	Box Mine Vic Lake	75.2
	Au	74-N-8	1	BQ	Athona Mine Lake Athabasca	109.5
Studer Mines Ltd.	(Cu, Ni)	74-A-B	Parts 5	Ext	S41286,287 Reef Lake	83.9

Table 2 - Stratigraphic Core Acquisitions (September 1, 1988 to August 31, 1989)

Company or Joint Venture Operator	*NTS Area*	*No. of Holes*	*Core Size*	*Property/Deposit Location by Lake*	*Length (m)*
Amok Ltd./ *Cluff Mining*	74-K-6	1	NQ, BQ	MPP 1005 Athabasca Group, Carswell Dome	approx. 1253
Cameco Skeleton Log Only Not Included in Total	74-G-6	Small Parts 5	BQ	MPP 1074 Athabasca Group Cree Lake	(467) (in one 6 m box)
Cominco	64-L-1+2 63-E-16	Upper Parts 8	NQ	Paleozoic Berland Project Cumberland Lake S99912 - 17 CBS 7915 - 23	approx. 823
	63-L-3 63-E-14+15	Upper Parts 3	NQ	Paleozoic Squaw Rapids Project MPP 1151 - 1161	approx. 402

properties drill-tested for base metals (44 percent), gold (42 percent), uranium (6 percent), gold and PGE (9 percent). The mineralized core collection is augmented by an extensive collection of rock samples from mineral properties in northern Saskatchewan. Important stratigraphic cores are housed in the Subsurface Geological Laboratory in Regina. Contributions to this "Northern Stratigraphic Core Collection" totalled some 2478 m in 1989 (Table 2), comprising cores from Paleozoic and Athabasca Group rocks.

1. References

Gracie, A.J. (1984): Mineralized core collection; *in* Summary of Investigations 1984, Sask. Geol. Surv., Misc. Rep. 84-4, p127-128.

______ (1985): Mineralized core collection; *in* Summary of Investigations 1985, Sask. Geol. Surv., Misc. Rep. 85-4, p82.

______ (1986): Mineralized core collection; *in* Summary of Investigations 1986, Sask. Geol. Surv., Misc. Rep. 86-4, p121-122.

______ (1987): Mineralized core collection; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p80-81.

______ (1988): Mineralized core collection; *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p125-126.

Gracie, A.J., Gray, L.J. and Boissoneault, G. (1987): Index to La Ronge core collection; Sask. Energy and Mines, Data File 12, 162p.

Three Precambrian Databases

R. Macdonald

Macdonald, R. (1989): Three Precambrian databases; *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

In this report, three Precambrian microcomputer-based data files are briefly described. These files were developed initially for in-house use, and are in various states of completion. Thanks mainly to the facilities offered by the microcomputer and its growing use these days in the hard rock geology and exploration field, the files are now being offered, informally at this stage, in the public domain. In response to interest received, these files will be modified and refined, and methods of data exchange and publication developed.

1. Saskatchewan Precambrian Bibliography

The Saskatchewan Precambrian Bibliography was started several years ago, under the title "Master Reference List", as an aid to authors preparing reference lists for reports and papers. The file was first implemented by R.F. Davie on a Wang word processor, and was subsequently transferred to an MS-DOS microcomputer using Sci-Mate software. The bibliographic references were classified into broad subject areas using keywords. Unfortunately Sci-Mate can only handle 20 data fields.

Realizing the limitations of the Sci-Mate software, the file has now been transferred to the database module of Q&A software (Symantec Corporation) where it only occupies about 10 percent of the available field space. The Q&A software was chosen because it offers greater flexibility and space for annotations, and also because of the ability to join or relate to other files already on the system. Q&A has good exporting capabilities and is not necessarily envisioned as permanent home for the file.

Although designed originally for Saskatchewan Precambrian references, the bibliography also contains references on provincial geology outside the Shield area. There is no reason why the file could not be extended to cover all aspects of Saskatchewan geology.

The present database contains over 3,000 records, with 20 fields based upon the original Sci-Mate fields. It is possible to design reports in a variety of formats and sortings for use in reference lists. Virtual or derived fields may also be created. The database has a "joining field" to other databases comprising a standardized "author/year" field.

2. Saskatchewan Precambrian Lexicon

The Precambrian Lexicon was started by the author in 1986 as an exploration into the names used in published reports or papers for stratigraphic, lithological, structural and other geological entities in the Precambrian of Saskatchewan. By means of the lexicon it was planned to trace back to the originators and the history of subsequent use of these terms. From this it should be possible to identify those terms which have not been formally defined, and then set up proposals for remedial action. The lexicon was also envisioned as eventually providing a vehicle for a systematic referenced description of regional geological features, available in computer-processable as well as hard copy form.

The file is housed on MS-DOS microcomputer, presently using Q&A database software. Each record in the database describes a reference to a name contained in a report or paper. There may be as many as 50 records or more from a single report. Over 4,000 records have been entered so far from over 500 reports.

The records are classified as primary, new data or citation references. A primary reference is of the first known usage of the term, and may in some cases qualify as a "type section" reference. A new data reference is one in which the author(s) provide new data for a previously established term. A citation is simply a reference to earlier work, mainly as part of a "General Geology" summary or for correlation purposes. Citation references are valuable in that they give an indication of the degree of acceptance of a term.

At this stage the Lexicon may still be regarded as a pilot project, and there has been no attempt to include all reports in it. The first approach in compiling the lexicon was to scan all relevant publications of Saskatchewan Energy and Mines (formerly Mineral Resources), and then to sample publications in refereed journals. Recently we have focussed on the older publications, in order to include early primary references. In selecting the papers, the Precambrian Bibliography has been useful.

An examination of the present file reveals some interesting features. As terms in the file are in the author's spelling, inconsistencies have become apparent in the way subsequent authors have cited terms. The lexicon also alerts us to terms, some highly quoted and accepted in the literature, which have never been formalized through "type section" descriptions in a refereed journal.

3. Saskatchewan Precambrian Geochronology Database

The Precambrian Geochronology file contains information on all known radiometric dating determinations of Precambrian rocks in the province. Included in each record are references to sample location (with coordinates), sample number, date sampled, laboratory and persons undertaking the work, methods used, results where available, publication reference etc. The file is backed up with location maps at 1:250,000 scale, presently only in manual (hard copy) form.

The file was initiated in manual form about 10 years ago, but received a quantum boost when placed on microcomputer four years ago. The file is also served by Q&A database software on MS-DOS microcomputers.

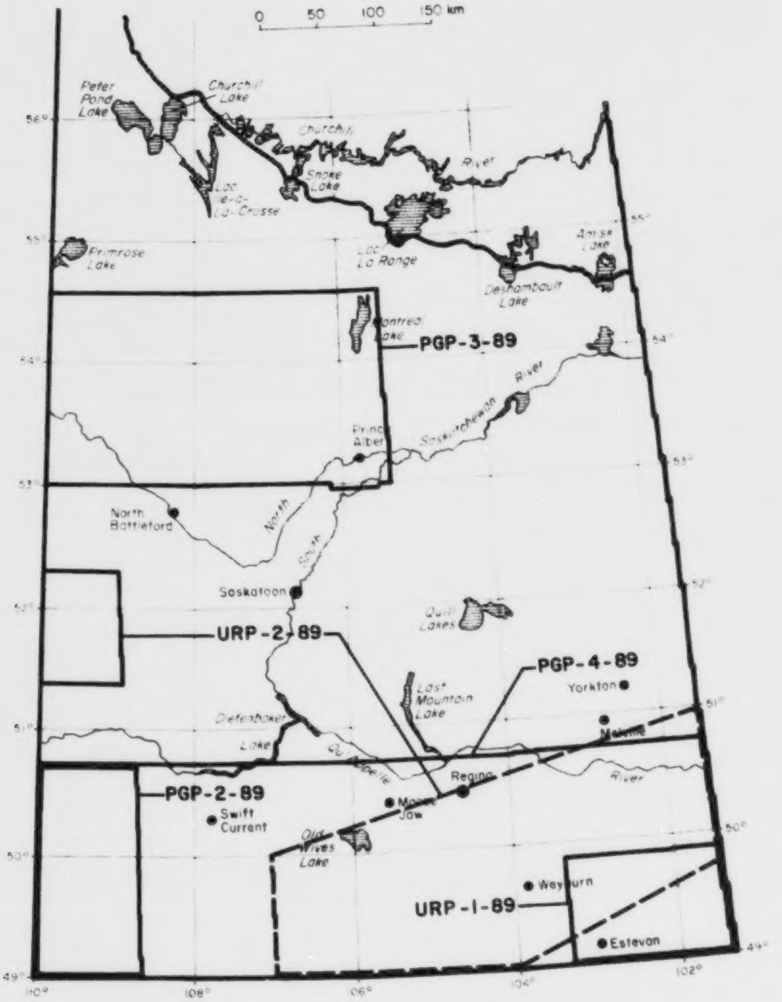
4. Future Development

With the introduction of version 3.0 of the Q&A software, files may now be joined in a relational manner. A common "joining field" is author(s) with year of publication. With this join it is now possible, for example, to produce a report on the results of a group of radiometric age determinations with a full bibliographic reference list or, in another example, produce page-referenced bibliographic listings of all reports which have data on a selected stratigraphic unit.

The Precambrian Lexicon could be developed into a new way of providing systematic regional geological data. At present the file is only a reference tool, but there seems to be a need for the inclusion of comments and annotations, as well as specific proposals for usage of terms. The file could also be augmented by scanning in text extracts or even graphics from reports.

Internal microcomputer networking now in progress in the department will facilitate the sharing, joining and security of the presently-described and other in-house databases. Ways and means of making the databases available externally are expected to follow, using not only hard copy reports, but even more through the development computer interaction by such media as CD-ROM disks. Efforts will also need to be directed to the development of standard data exchange formats for industry and others, an endeavour which the Association of Provincial Geologists has already started work on, on a Canada-wide basis. Plans are also in hand for development of a Geographic Information System in the Geology and Mines Division to handle the graphical as well as textual/numeric information. In all of these endeavours close and ongoing discussions with all users will be imperative.

Petroleum Geology Program


0 50 100 150 km
Peter Pond Lake
Churchill Lake
Churchill River
Lac Île-à-la-Crosse
Snake Lake
Primrose Lake
Lac La Ronge
Amisk Lake
Deschambault Lake
Montreal Lake
PGP-3-89
Saskatchewan River
Prince Albert
North Battleford
North
South
Saskatoon
Quill Lakes
URP-2-89
PGP-4-89
Yorkton
Last Mountain Lake
Diefenbaker Lake
Qu'Appelle River
Regina
PGP-2-89
Swift Current
Moose Jaw
Old Wives Lake
Weyburn
URP-1-89
Estevan
56°
55°
54°
53°
52°
51°
50°
49°
110°
108°
106°
104°
102°

Location of Petroleum Geology projects supported by Petroleum Geology Branch

Petroleum Geology Projects

PGP-1-89:	The Earlie Formation (Cambrian) in Saskatchewan: Doug Paterson (Not shown on map, covers all of Saskatchewan south of the Precambrian Shield)
PGP-2-89:	Geology and Natural Gas Production of the Upper Cretaceous Medicine Hat Sandstone, Southwestern Saskatchewan: Chris Gilboy
PGP-3-89:	Distribution of Lower Paleozoic strata in the vicinity of the Meadow Lake Escarpment, West-Central Saskatchewan: Fran Haidl
PGP-4-89:	Palynology of the Shaunavan and Gravelbourg Formations of Southern Saskatchewan: Kim Kreis

University of Regina Projects supported by Petroleum Geology

URP-1-89:	Preliminary report on a pore geometry reservoir model for the carbonate buildups in the Winnipegosis Formation (Devonian) in southeast Saskatchewan: Melinda Yurkowski
URP-2-89:	Sedimentology and Geochemistry of the Bakken Formation (Devonian-Mississippian) in southern Saskatchewan: Ramez Karma and Geoff Parslow (Two separate areas)

The Earlie Formation (Cambrian) in Saskatchewan

D.F. Paterson

Paterson, D.F. (1989): The Earlie Formation (Cambrian) in Saskatchewan; *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

The Earlie Formation was the name used by Pugh (1971) for "the sequence of interbedded, glauconitic siltstones and fine-grained sandstones and shales, that overlies the basal sandstone unit and is, in turn, overlain by the siltstone and shale facies of the Deadwood Formation in the subsurface of eastern Alberta". He recognised, as did Aitken (1968) and van Hees (1964), that the Middle Cambrian limestones and shales of the Alberta foothills changed to sandstones and siltstones as they were traced eastwards. Thus the Earlie Formation in eastern Alberta comprises, from oldest to youngest, the Mount Whyte, Cathedral, Stephen, Eldon and Pika Formations of the west.

Those formations were deposited on a Precambrian basement which rose in elevation eastwards, resulting in the lower strata being restricted to the west as the upper strata progressively overlapped them to the east. Thus, in southern Saskatchewan, the equivalents of the Mount Whyte and Cathedral Formations are likely absent and the Earlie thus represents the Stephen, Eldon and Pika Formations.

Geologists in Saskatchewan have hitherto recognised only the Deadwood Formation (Upper Cambrian to Ordovician) in the west though van Hees (1964) and Paterson (1988) pointed out that there should be Middle Cambrian strata present. In this study, the contact of the Earlie and Deadwood Formations in Alberta has been extended eastwards into Saskatchewan and followed to its limits through geophysical log correlations, thus properly restricting the Deadwood above and illustrating the presence of the Earlie below.

The "basal sandstone unit" of Pugh (1971) and "basal clastic unit" of van Hees (1964), informal designations of the generally coarse clastic strata that immediately overlie the Precambrian basement, are thought to be diachronous. This study has not attempted to define the unit but has treated it as a basal unit of the overlying formation.

The geophysical log in Figure 1 shows distinctly different responses of the Earlie and Deadwood Formations. The Earlie has overall lower readings on the gamma ray trace while showing slightly higher and less fluctuating values on the borehole compensated sonic. This reflects their lithological compositions, which are further elucidated with information from drill cuttings. The interpretation is that the Earlie comprises coarse- to medium-grained, quartzose, glauconitic sandstones interbedded with siltstones and shales. The Deadwood contains more thinly interbedded, fine-grained, quartzose, glauconitic sandstones, siltstones and shales. The log also shows lower gamma ray values and higher BCS values in the Ordovician dolomites above the Deadwood.

All available geophysical logs in Saskatchewan and many in eastern Alberta have been used to construct preliminary cross-sections of the strata between the Ordovician dolomites and the Precambrian basement. These sections will be checked and necessary corrections made before being published in a final report. Some will also be included in the new Geological Atlas of the Western Canada Sedimentary Basin which is presently being compiled under the guidance of Dr. Grant D. Mossop at the Alberta Geological Survey in Edmonton.

Figures 2 and 3 are preliminary maps only, constructed from a SYMPHONY database and SURFER mapping package, produced on an EPSON dot matrix printer. Figure 2 is an isopach map of the Earlie Formation (including the basal clastic unit as explained above). The strata thin to the east and pinch out along a line just west of Moose Jaw and just east of Prince Albert. They are also absent in the extreme north.

Three major regions are indicated by the new isopach map:

1. In the southwest, from north of Swift Current to the U.S. Border, the formation is generally less than 100 m thick and the contours show a scatter of thicks and thins. Four monadnocks of Precambrian rock lie along a line from just northwest of Swift Current to the Alberta - Saskatchewan - U.S. borders. Projecting this line to the northeast reveals another monadnock to the southeast of Saskatoon and on the projected line lies the "Elbow structure" which is approximately 110 km northwest of Moose Jaw.

2. North of Swift Current, the strata are generally over 100 m thick and reach 229 m at a location 70 km east of Lloydminster. To the north of this they thin steadily to zero over a distance of 100 km. This is the "Lloydminster Embayment" of van Hees (1964).

3. The northern limit of the Earlie shows dramatic thinning along an east - west line some 60 km or so north of Lloydminster. This is in the general area of the Meadow Lake Escarpment, usually considered to be a Devonian structure. The map presented here suggests that the Precambrian surface rose in elevation rather steeply to the north and limited the deposition of the formation to the area shown. By implication, Cambrian strata now present to the north of this is inferred as Deadwood and was eroded during the formation of the escarpment. Van Hees

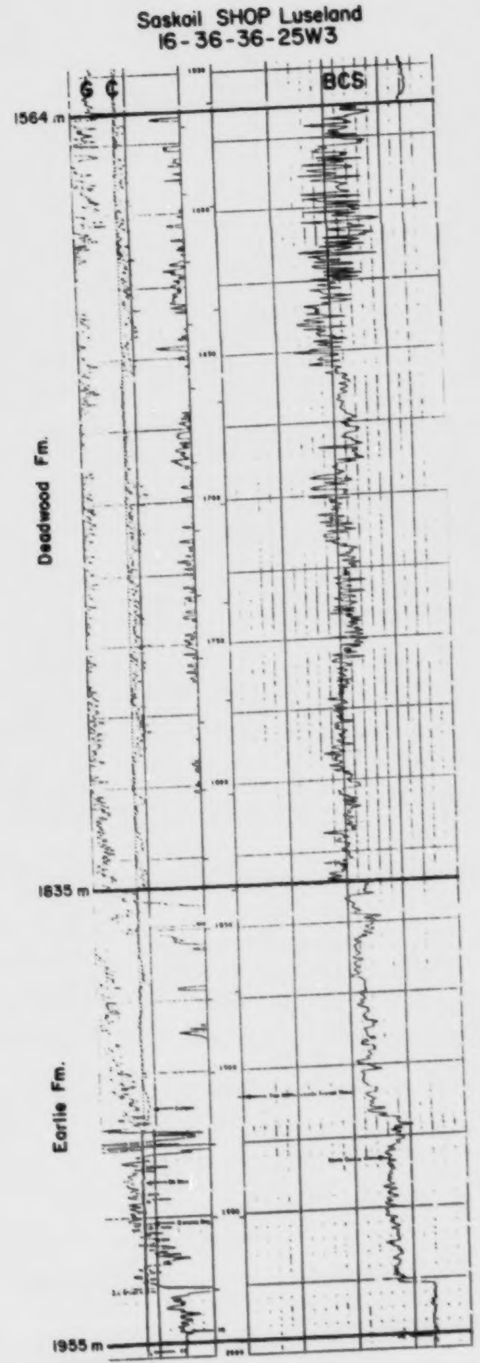


Figure 1. Geophysical log from the well Saskoil SHOP Luseland 16-36-36-25W3 showing Deadwood top at 1564 m and Deadwood - Earlie contact at 1835m. G = Gamma trace; C = Caliper trace; BCS = Borehole Compensated Sonic trace.

(1964) has both the Earlie and Deadwood extending to the north before being uplifted and eroded in the Devonian. In his model the most northerly strata now present are Earlie, which occupies the position by erosional offlap. Further detailed study may resolve this issue.

The structure map on top of the Earlie (Figure 3) shows the surface to have a general southwesterly dip from 249 m above sea level in the northeast to some 1575 m or so below sea level in the south. This is a gradient of approximately 1 in 300 (one-fifth of a degree!). Only in the area south of Swift Current and Maple Creek is there any substantial departure from this regional plane. The irregularities there could well be a reflection of Laramide earth movements which are well known to the south and west. There is no obvious evidence at the formation's northern limit of the Meadow Lake Escarpment.

1. References

Aitken, J.D. (1968): Cambrian sections in the easternmost southern Rocky Mountains and the adjacent subsurface, Alberta; Geol. Surv. Can., Pap. 66-23.

Paterson, D.F. (1988): Review of regional stratigraphic relationships of the Winnipeg Group (Ordovician), the Deadwood Formation (Cambro-Ordovician) and underlying strata in Saskatchewan; *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p224-225.

Pugh, D.C. (1971): Subsurface Cambrian stratigraphy in southern and central Alberta; Geol. Surv. Can., Pap. 70-10.

van Hees, H. (1964): Cambrian; *in* McCrossan, R.G. and Glaister, R.P. (eds.), Geological History of Western Canada; Alta. Soc. Petrol. Geol., Calgary, Ch3, Pt1,p20-28.

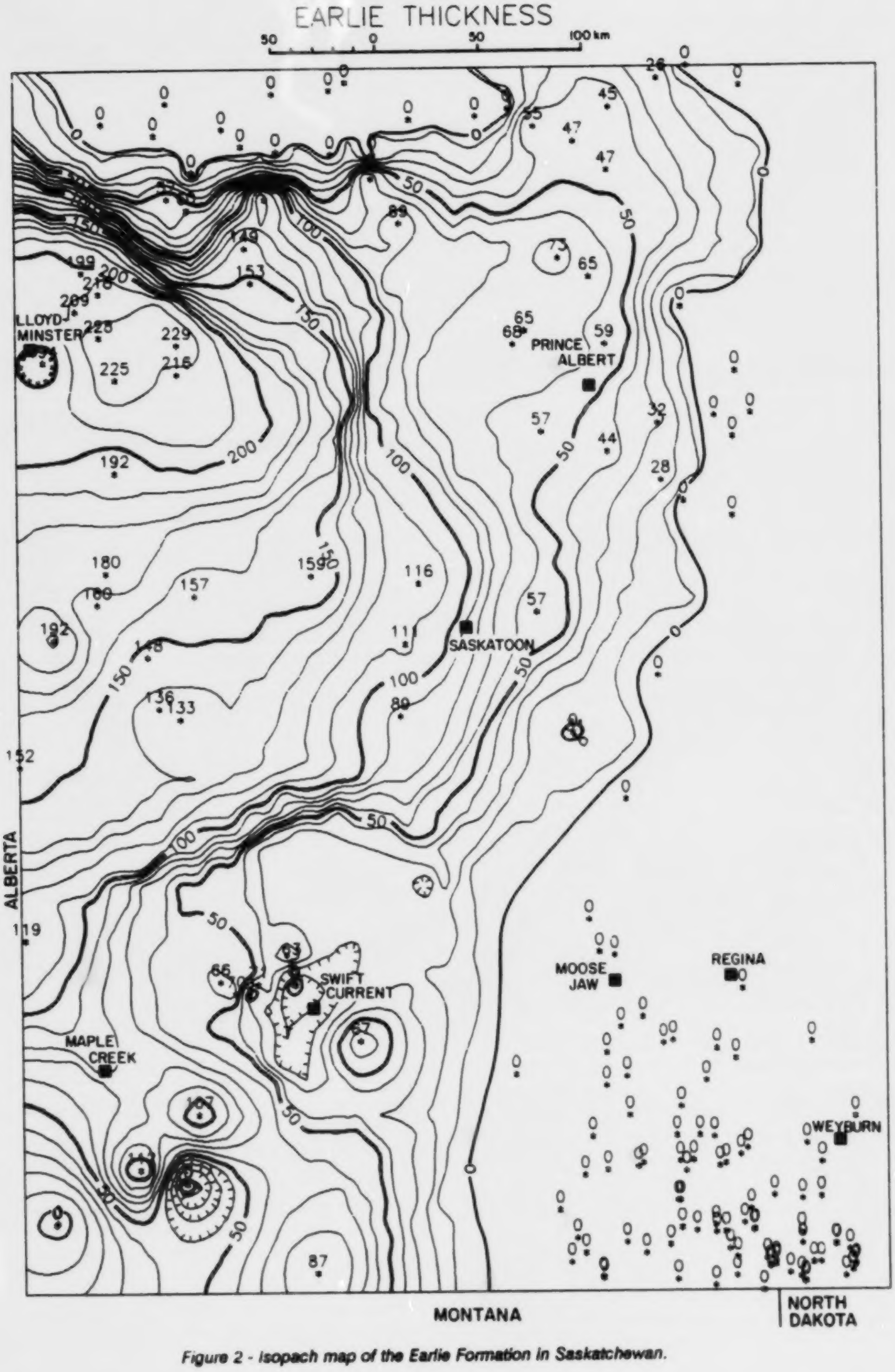

EARLIE THICKNESS
50
0
50
100 km
LLOYDMINSTER
PRINCE ALBERT
SASKATOON
SWIFT CURRENT
MAPLE CREEK
MOOSE JAW
REGINA
WEYBURN
ALBERTA
MONTANA
NORTH DAKOTA
0
50
100
150
200
45
47
47
89
149
153
199
216
209
228
229
225
216
73
65
65
68
59
57
44
32
28
192
180
180
157
159
116
192
148
111
57
136
133
80
152
119
66
67
107
87

Figure 2 - Isopach map of the Earlie Formation in Saskatchewan.

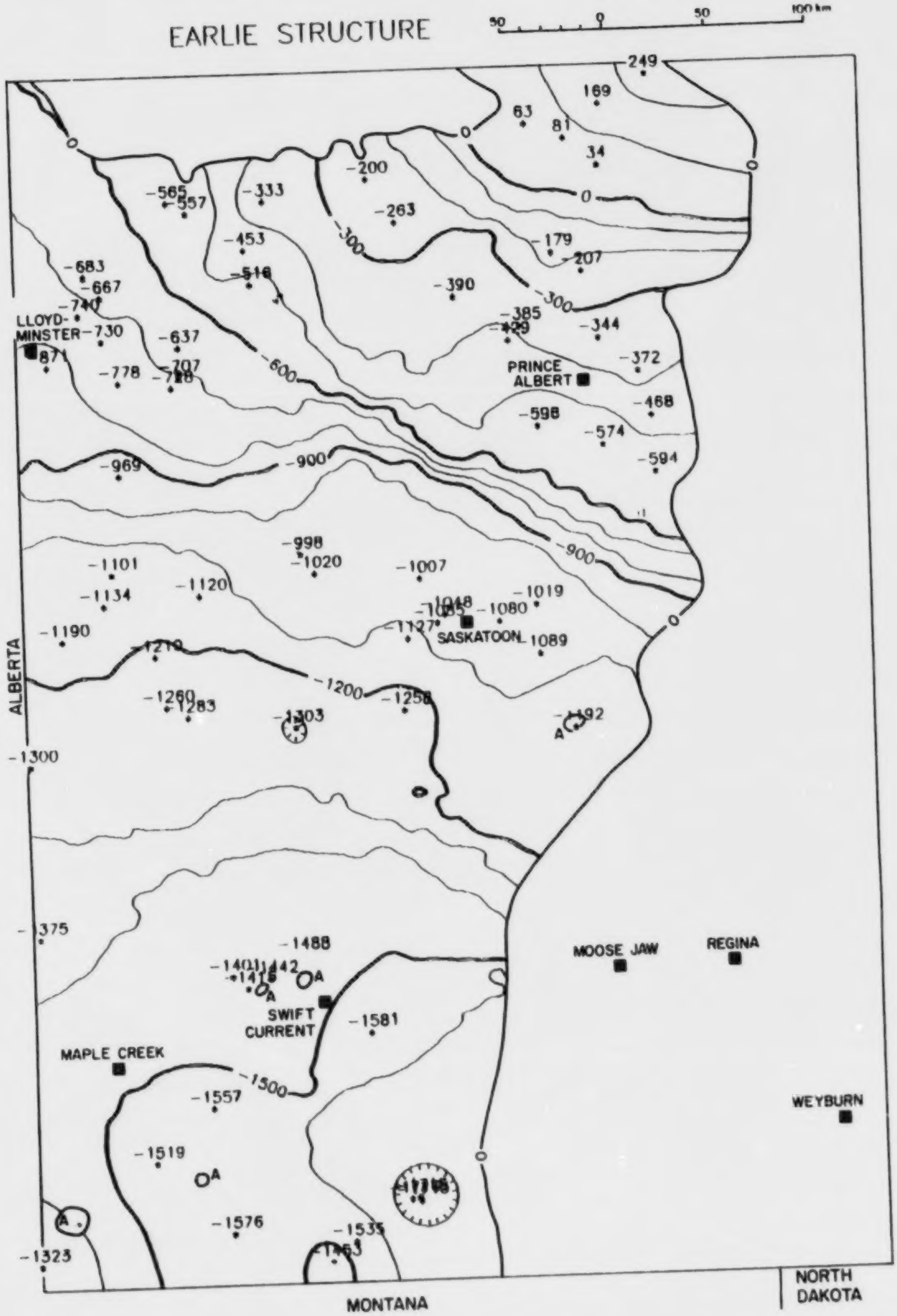

EARLIE STRUCTURE
50
0
50
100 km
LLOYD-MINSTER
PRINCE ALBERT
SASKATOON
MOOSE JAW
REGINA
SWIFT CURRENT
MAPLE CREEK
WEYBURN
ALBERTA
MONTANA
NORTH DAKOTA
0
-300
-600
-900
-1200
-1500
A
249
169
63
81
34
-200
-333
-565
-557
-263
-453
-516
-179
-207
-390
-385
-429
-344
-372
-683
-667
-740
-730
-871
-637
-707
-728
-778
-468
-598
-574
-594
-969
-998
-1020
-1007
-1101
-1134
-1120
-1019
-1048
-1085
-1080
-1127
-1089
-1190
-1210
-1260
-1283
-1303
-1258
-1192
-1300
-1375
-1488
-1401
-1442
-1416
-1581
-1557
-1519
-1576
-1535
-1463
-1323

Figure 3 - Structure map on top of the Earlie Formation. Formation limit is zero isopach line from Figure 2. A = Formation absent.

Geology and Natural Gas Production of the Upper Cretaceous Medicine Hat Sandstone, Southwestern Saskatchewan

C.F. Gilboy

Gilboy, C.F. (1989): Geology and natural gas production of the Upper Cretaceous Medicine Hat Sandstone, southwestern Saskatchewan; *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

The Medicine Hat Sandstone, upper Coniacian to lower Santonian in age, is close to the top of Colorado Group strata in southeast Alberta and southwest Saskatchewan. It is of both economic and historical significance in that it contains the largest and oldest gas pool in Canada. The Medicine Hat Sandstone is stratigraphically equivalent to the Martin Sandstone (Niobrara Formation) in north-central and eastern Montana (Rice, 1981; Gilboy, this paper).

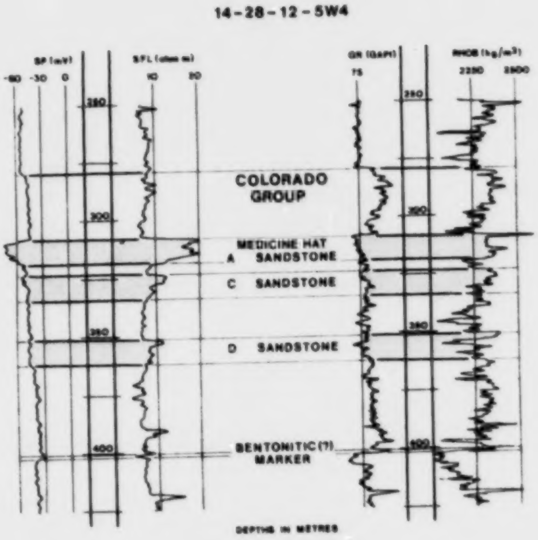
1. Previous Work

Despite a high drilling density and the consequent large amount of log data available for the Medicine Hat Sandstone, specifically relevant geological studies have only rarely been published (Martin, 1965; Hancock and Glass, 1968; Kendall and Simpson, 1974; Simpson, 1981; Hankel *et al.*, 1989). Several consultants' reports (e.g. Last, Kloepfer Ltd., 1973; Martin Petroleum Consulting Ltd., 1985) contain useful assessments of the regional geology of the sandstone.

2. Nomenclature

The type locality for the Medicine Hat Sandstone is the City of Medicine Hat in southeast Alberta, where a well drilled in 1890 in search of coal encountered a considerable flow of wet gas at a depth of about 200 m (and therefore probably from the Milk River Formation). The follow-up well drilled in 1904 discovered a larger supply of drier gas at about 310 m from the Medicine Hat Sandstone. Rigorous definitions of this and enclosing lithological units appear not to have been published. Current nomenclature is, therefore, largely based on popular usage, particularly that established by Alberta's Energy Resources Conservation Board.

Three separate gas-producing sandy horizons are widely developed over an approximately 50 m wide vertical section underlying the shale at the top of the Colorado Group (the First White-speckled Shale, see Figure 1 and Section B-B' in map holder). These have been named, from the top down, Medicine Hat A, C and D Sandstones, following pool designations used by the Energy Resources Conservation Board (1975, 1977). The Medicine Hat B Sandstone is no longer recognised as the name originally including parts of the C and D Sandstones (Energy Resources Conservation Board, 1975). In recent years, reference has increasingly been made to the Medicine Hat Formation (Energy Resources Conservation Board, 1975; Warren, 1985; Hankel *et al.*, 1989) but without clear explanation of the stratigraphic interval encompassed by this unit. Warren (1985) shows a type log (in Figure 4 of his paper) which suggests the Medicine Hat Formation extends from the base of the First White-speckled Shale to about the top of a regionally developed bentonitic(?) marker horizon (immediately below which Rice (1981) places the top of the Carlile Shale in northern Montana; see also Gilboy, this paper).



PRODUCING HORIZONS, MEDICINE HAT FIELD, SE ALBERTA

Figure 1 – Electric, gamma ray and lithodensity logs of a typical producing well in southeastern Alberta, showing signatures of the three main Medicine Hat producing horizons (the well is located immediately east of the City of Medicine Hat).

Although stratigraphic terminology in the western Canadian Great Plains region is generally unsatisfactory, it is deeply entrenched in existing literature and may be difficult to change. For example, Meijer Drees and Myhr, (1981), carefully defined the Alderson Formation as the marine equivalent of the Milk River Formation, but their work seems to have gained little acceptance by other workers in this field who are overwhelmingly familiar with the Milk River Formation as being the sandier equivalent of Lea Park Formation shales.

3. Lithology

The Medicine Hat Sandstone does not crop out in either southeastern Alberta or southwestern Saskatchewan. In the study area (Figure 2), it has been cored in 25 wells, the majority of which are situated in the Hatton Gas Field (Rgs. 27 to 30W3, Twps. 13 to 16 inclusive). The condition of recovered core is only fair in most of these wells owing to poor consolidation of the rock and a moderately high content of expandable clay minerals. Stratigraphic cross-sections from southeast Alberta into southwest Saskatchewan (Gilboy, this paper) show that the cored (gas-producing) interval in the Hatton-Burstall area is laterally continuous with the Medicine Hat A Sandstone. The D Sandstone is also recognizable on geophysical logs (Figure 3), but barely so as it gradually shales out towards the northeast.

The most abundantly preserved sedimentary structures include fine parallel lamination, low-angle current rippled sand layers one to two centimetres thick, starved ripples, and normally-graded bedding (layers several centimetres thick). Several of these features are illustrated in Plate 1. Small-scale erosion surfaces with up to about one centimetre relief are also present, though rare, as are thin coquinoid layers (Plate 2). Sand grain size is mostly in the 88 to 125 micron range, but locally reaches 125 to 177 microns. Grains are subrounded to subangular. Rare bentonitic horizons occur at different levels through the Medicine Hat Sandstone, which is moderately calcareous throughout its thickness.

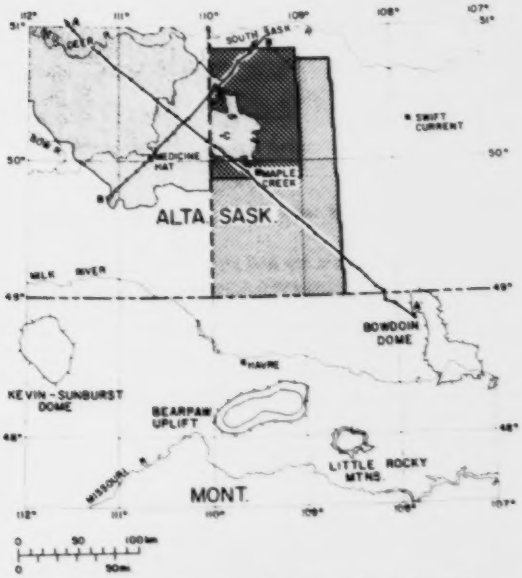


Figure 2 – Natural gas fields (stippled), Medicine Hat Sandstone, northern Great Plains region, showing locations of: 1) the study area (diagonally hatched); 2) parts of the stratigraphic cross-section lines which transect the area covered by the map (A-A', B-B'); 3) the location (c) of the well used in Figure 3; 4) the area covered by the structure and cumulative gas-production map in Figure 4 (cross-hatched); and 5) major tectonic uplifts (hachured).

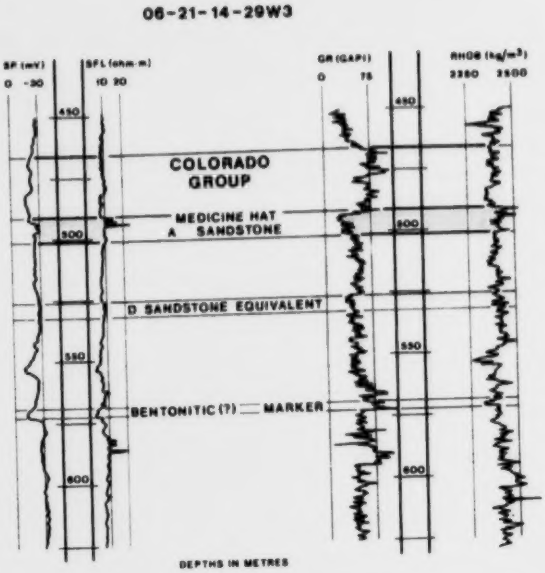


Figure 3 – Electric, gamma ray and lithodensity logs from a typical Medicine Hat producing well in the Hatton Gas Field, southwestern Saskatchewan

Bioturbated layers a few centimetres thick are common (Plate 1), but identifiable trace fossils have yet to be found. Organic remains in the Medicine Hat Sandstone include, in addition to the coquinoid shell debris, white specks presumably made up of coccoliths and coccospheres, fish bones and scales, *Inoceramus* fragments, lignitic plant remains, and rare ammonite shells.

4. Depositional Environment

Graded bedding and parallel laminations, along with local shell-rich layers, suggest that the sediments of the Medicine Hat A Sandstone were probably deposited as a result of storm activity. Coccolithic shales may have accumulated during inter-storm periods. The presence of ammonites attests to the marine origin of these rocks. The relatively high clay content of the sands, their very fine grain size, and sedimentary structures indicate a prodelta environment of deposition.

5. Natural Gas Production

In southwest Saskatchewan, the first well (10-23-14-30W3) to produce from the Medicine Hat Sandstone was drilled in 1953 in the Hatton area. Currently, 505 wells produce sweet dry methane from this stratigraphic interval, and an additional 845 wells deliver co-mingled Medicine Hat-Milk River gas. In 1972, Medicine Hat gas was discovered to the north in the Burstall area, where 5

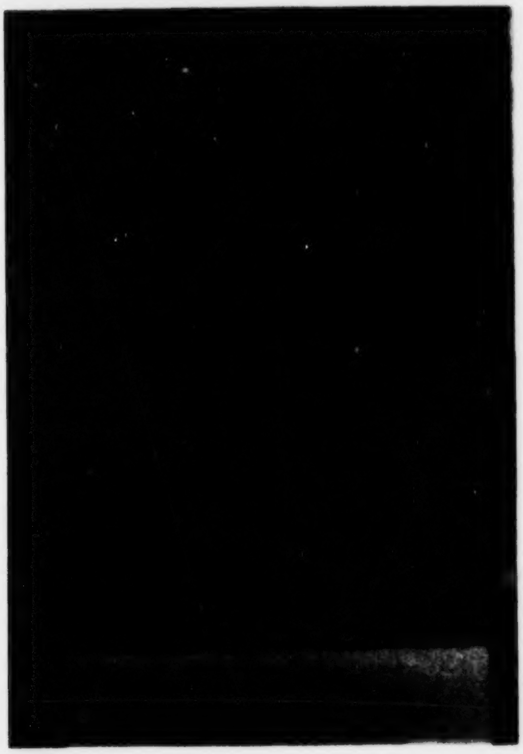


Plate 1 – Bioturbated shaly sand lying between layers of finely laminated, very fine-grained sandstone, siltstone and shale; these rest upon a thin band of coarser-grained, carbonate-cemented, ripple-bedded sandstone (from well 07-22-09-28W3M, 641.3 m below Kelly Bushing).

wells now produce solely from this reservoir and 55 comingle Medicine Hat and Milk River gas. Initial gas in place in the Medicine Hat Sandstone is estimated to be approximately 20 x 10^6 m^3 (Saskatchewan Energy and Mines, in press). The most highly productive area (using cumulative figures) lies along the border between Saskatchewan and Alberta (Figure 4), towards the shallowest up-dip region of the sandstone. Higher up-dip, in Twp. 12, some wells encounter water problems, and a similar up-dip water-trap mechanism to that proposed by Hankel *et al.*, (1989) appears to apply. Structure contour maps on the top of the Medicine Hat Sandstone (Mahnic, 1989a,b) show that this surface is gently warped along northwest-southeast and southwest-northeast axes. This cross-folding has produced shallow domes and basins. The cumulative production pattern bears no obvious relationship to these structures, which therefore appear not to have major control on gas accumulation in this area. Elsewhere in southwestern Saskatchewan, however, such structures might be important.

6. References

Energy Resources Conservation Board (1975): Zone terminology and pool designations in the Medicine Hat Formation (attachment to examiners' report on Application no. 8981).

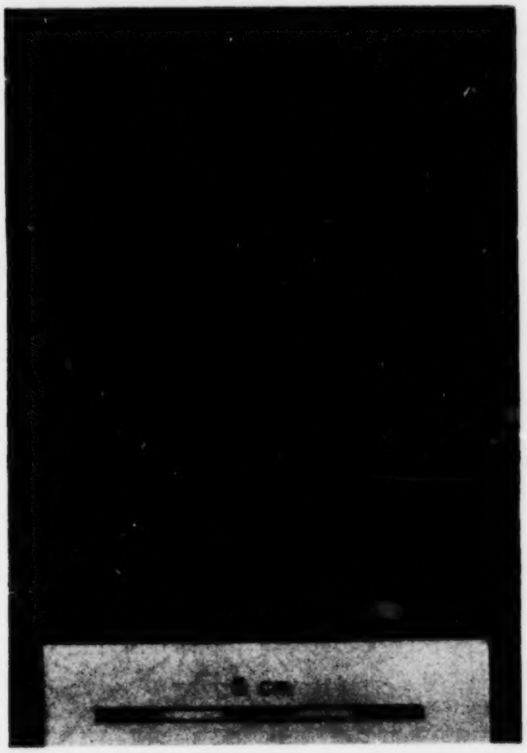


Plate 2 – Thin coquinoid band overlying laminated sandstone in which lamination is locally disrupted, possibly by dewatering, and overlain by several one- to two-centimetre thick, normally graded beds.

__________(1977): Relationship between the Medicine Hat Zone of zone designation no. 390 and the Medicine Hat A, C and D pools (attachment to Decision 77-9 respecting Application no. 770202).

Hancock, W.P. and Glass, D.J. (1968): Medicine Hat – Hatton Gas Field, Alberta and Saskatchewan; *in* Beebe, D.W. (ed.), Natural Gases of North America; Am. Assoc. Petrol. Geol. Bull., Mem.9, v1, p731-735.

Hankel, R.C., Davies, G.R. and Krouse, H.R. (1989): Eastern Medicine Hat gas field : a shallow, Upper Cretaceous, bacteriogenic gas reservoir of southeastern Alberta; Bull. Can. Petrol. Geol., v37, p98-112.

Kendall, A.C. and Simpson, F. (1974): Calcite layers in the uppermost Medicine Hat Sandstone (Upper Cretaceous) of southwestern Saskatchewan; Bull. Can. Petrol. Geol., v22, p34-41.

Last, Kloepfer Ltd. (1973): Shallow gas reserve potential, southeast Alberta and southwest Saskatchewan, Townships 10 to 25, Ranges 25W3M to 20W4M : a study prepared for Dome Petroleum Ltd.; Last, Kloepfer Ltd., Calgary, 26p.

Mahnic, P. (1989a): Structural contours on the Medicine Hat Sandstone, Liebenthal area; Sask Energy Mines, Map K-14(N)-2.

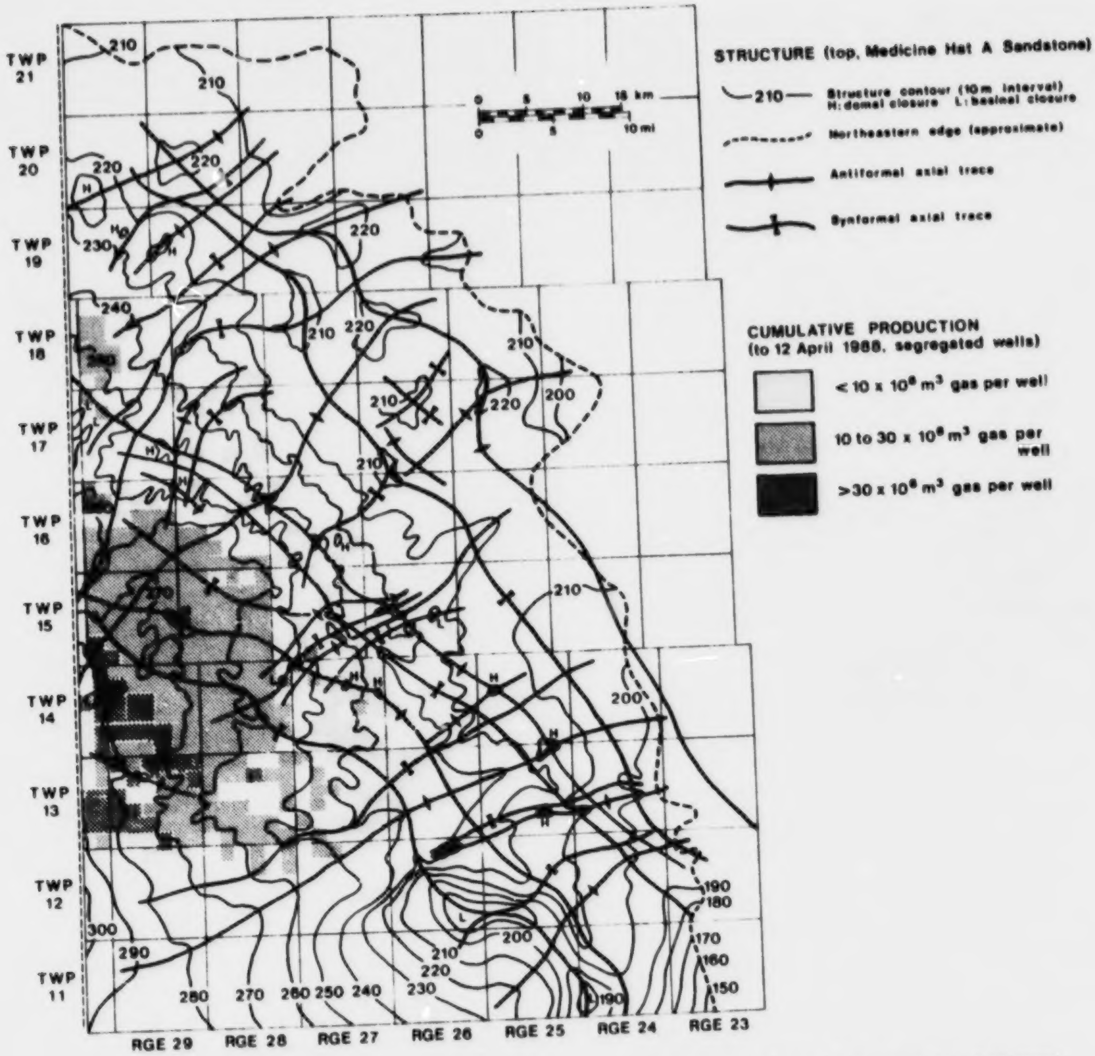

STRUCTURE (top, Medicine Hat A Sandstone)
210 Structure contour (10 m interval) H: domal closure L: basinal closure
Northeastern edge (approximate)
Antiformal axial trace
Synformal axial trace
CUMULATIVE PRODUCTION (to 12 April 1988, segregated wells)
< 10 x 10⁶ m³ gas per well
10 to 30 x 10⁶ m³ gas per well
>30 x 10⁶ m³ gas per well
0 5 10 15 km
0 5 10 mi
TWP 21
TWP 20
TWP 19
TWP 18
TWP 17
TWP 16
TWP 15
TWP 14
TWP 13
TWP 12
TWP 11
RGE 29
RGE 28
RGE 27
RGE 26
RGE 25
RGE 24
RGE 23
210
220
230
240
200
190
180
170
160
150
300
290
280
270
260
250
H
L

Figure 4 – Structure and cumulative gas-production map, Hatton-Burstall Fields (see Figure 2 for location) and adjacent area, southwestern Saskathewan; structure contours from Mahnic (1989a,b).

________ (1989b): Structural contours on the Medicine Hat Sandstone, Hatton area; Sask Energy Mines, Map K-14(S)-2.

Martin, I. (1965): The Medicine Hat Gas Field; J. Can. Petrol. Tech., 1965, p23-29.

Martin Petroleum and Consulting Ltd. (1985): Reservoir study of the Medicine Hat Field for Many Islands Pipe Lines (Canada) Ltd.

Meijer Dress, N.C. and Mhyr, D.W. (1981): The Upper Cretaceous Milk River and Lea Park Formations in southeastern Alberta; Bull. Can. Petrol. Geol., v29, p42-74.

Rice, D.D. (1981): Subsurface cross-section from southeastern Alberta, Canada, to Bowdoin Dome area, north-central Montana, showing correlation of Cretaceous rocks and shallow, gas-productive zones in low-permeability reservoirs; U.S. Geol. Surv., Oil and Gas Invest. Chart OC-112.

Saskatchewan Energy and Mines (in press): 1988 Reservoir Annual.

Simpson, F. (1981): Low-permeability gas reservoirs in marine Cretaceous sandstones of Saskatchewan : 11. Well-log analysis of Medicine Hat Sandstone (Santonian) of southwestern Saskatchewan and southeastern Alberta; *in* Summary of Investigations 1981, Sask. Geol. Surv., Misc. Rep. 81-4, p159-162.

Warren, A. (1985): Southeastern Alberta shallow gas pools reserves and performance data; Alta. Resour. Conserv. Board Bull., 18p.

Distribution of Lower Paleozoic Strata in the Vicinity of the Meadow Lake Escarpment, West-Central Saskatchewan

F.M. Haidl

Haidl, F.M. (1989): Distribution of Lower Paleozoic strata in the vicinity of the Meadow Lake Escarpment, west-central Saskatchewan; *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

This study was undertaken to provide data necessary to delineate the northern limits of Ordovician and Silurian strata on maps generated for the New Geologic Atlas of Western Canada Sedimentary Basin, and to further ongoing research by the author on the Silurian sequence in Saskatchewan (Haidl, 1987, 1988). The paper summarizes results from 73 wells in an area encompassing Townships 47 to 64, Range 24W2 to the Alberta border (Figure 1). Stratigraphic correlations of Ordovician and Silurian carbonates were established using geophysical logs and drill cuttings. Data from the Cambrian and Ordovician clastic sequence are from Paterson (1971) and from an ongoing regional study by D.F. Paterson, who kindly made available these new data.

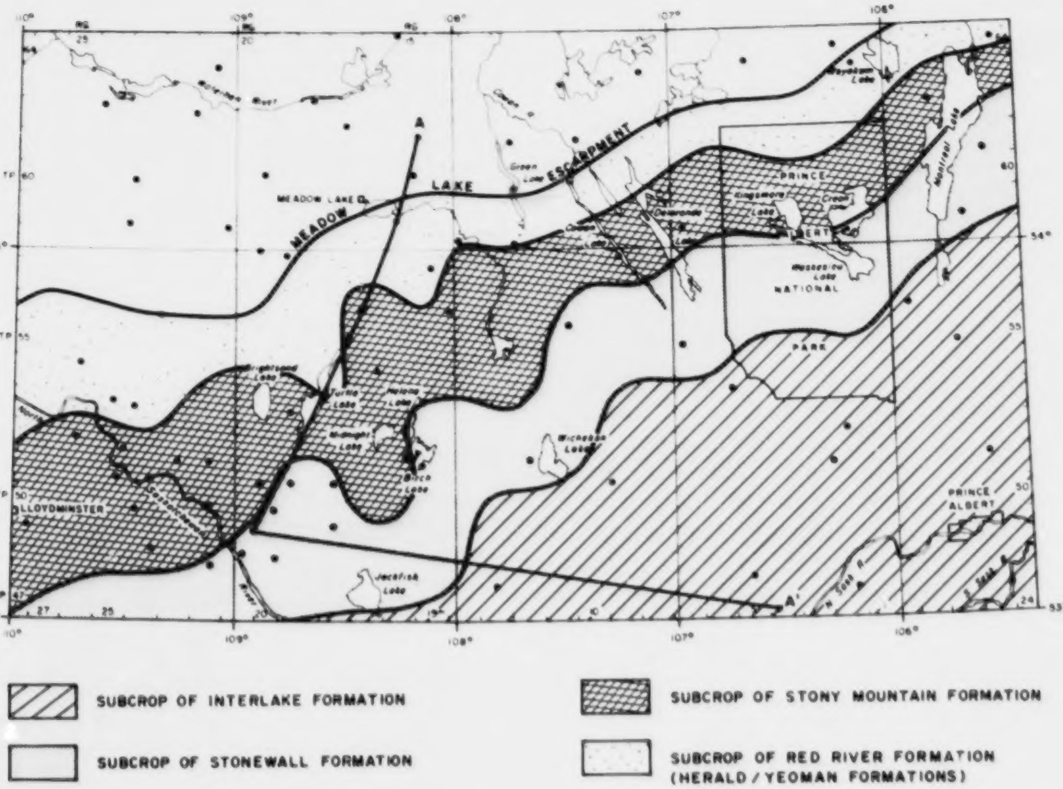

110°
109°
108°
107°
106°
54°
53°
TP 60
TP 55
TP 50
TP 47
RG 25
20
15
10
A
A'
MEADOW LAKE ESCARPMENT
MEADOW LAKE
PRINCE ALBERT NATIONAL PARK
LLOYDMINSTER
PRINCE ALBERT
SUBCROP OF INTERLAKE FORMATION
SUBCROP OF STONY MOUNTAIN FORMATION
SUBCROP OF STONEWALL FORMATION
SUBCROP OF RED RIVER FORMATION (HERALD / YEOMAN FORMATIONS)

Figure 1 – Subcrop map of Lower Paleozoic carbonates in the study area. The erosional edge of the Red River Formation defines the Meadow Lake Escarpment, a northwest-facing slope formed by differential erosion of Red River carbonates and Deadwood/Earlie clastics. The location of cross section A-A' (Figure 2) is shown by a heavy black line.

1. Geologic Setting

Lower Paleozoic strata in Saskatchewan were deposited on the Interior Platform component of the Western Canada Sedimentary Basin (Aitken, in press; Osadetz and Haidl, in press). These deposits encompass the two lowermost major unconformity-bounded sequences of Sloss (1963), the Sauk Sequence and Tippecanoe Sequence. In west-central Saskatchewan, Sauk Sequence strata are composed entirely of clastics (Deadwood and Earlie Formations) of Middle Cambrian to Early Ordovician age. A major unconformity separates these clastics from the basal clastic unit of the Tippecanoe Sequence, the Winnipeg Formation (Middle Ordovician), which is present only in the eastern portion of the study area (Table 1). The remainder of the Tippecanoe Sequence is composed of carbonates of Late Ordovician to Early Silurian age. This carbonate sequence was deposited in the ancestral Williston Basin with northern depositional limits that probably extended well beyond the study area, but uplift on the northern margin during the pre-Devonian erosion period resulted in substantial truncation of Lower Paleozoic strata (van Hees, 1958, 1964). At the erosional margin of resistant Ordovician carbonates (Figure 2), more rapid erosion of less resistant Deadwood/Earlie clastics formed a relatively steep northwest-facing slope, the Meadow Lake Escarpment (van Hees, 1958). North of this escarpment, pre-Devonian erosion also removed up to 300 m of Sauk Sequence strata (van Hees, 1958, 1964).

Following the initial transgression of Middle Devonian seas, a complex sequence of evaporites, carbonates, and clastics (Meadow Lake Fm., Fuzesy, 1980; Meadow Lake Beds, van Hees, 1956; Buller, 1958) were deposited in the Lower Elk Point Basin. Distribution of these strata indicate that the approximate southern shoreline of this basin was, at that time, formed by the Meadow Lake Escarpment, along the northeast-southwest curvilinear trend of the erosional edge of the Red River Formation (van Hees, 1958). Later transgression of the sea southwards across the Escarpment resulted in deposition of the argillaceous dolomites, dolomitic shales, and minor anhydrites of the Ashern Formation (van Hees, 1958; Buller 1958; uppermost beds, Meadow Lake Fm., Fuzesy, 1980). At the close of Ashern deposition, the Meadow Lake Escarpment was buried by Devonian sediments (Figure 2).

In the northeast corner of the study area (wells in Twp. 61 and 64, Rge. 24W2; Twp. 63, Rge. 1W3, Table 1), truncation of Devonian and Lower Paleozoic strata occurred during the pre-Cretaceous erosion period. In this area, Lower Cretaceous sandstones of the Mannville Group overlie Ordovician carbonates.

2. Stratigraphy

a) Deadwood and Earlie Formations

Historically, the siltstones, shales, and sandstones which comprise the basal sedimentary sequence in western Saskatchewan have been assigned to the Deadwood Formation (Fyson, 1961; Fuzesy, 1980). Recent work by Paterson (1988; this volume) suggests that the lower portion of the sequence is Middle Cambrian in age and correlates with the Earlie Formation defined in eastern Alberta (Pugh, 1971). The remainder of the sequence correlates with the Deadwood Formation which is assigned a Late Cambrian to Early Ordovician age (Paterson, 1988; Lefever *et al.*, 1987; Pugh, 1971).

In east-central Alberta, the Earlie Formation is composed of "interbedded, glauconitic siltstones and fine-grained sandstones and shales" (Pugh, 1971, p7) and the Deadwood Formation consists of interbedded

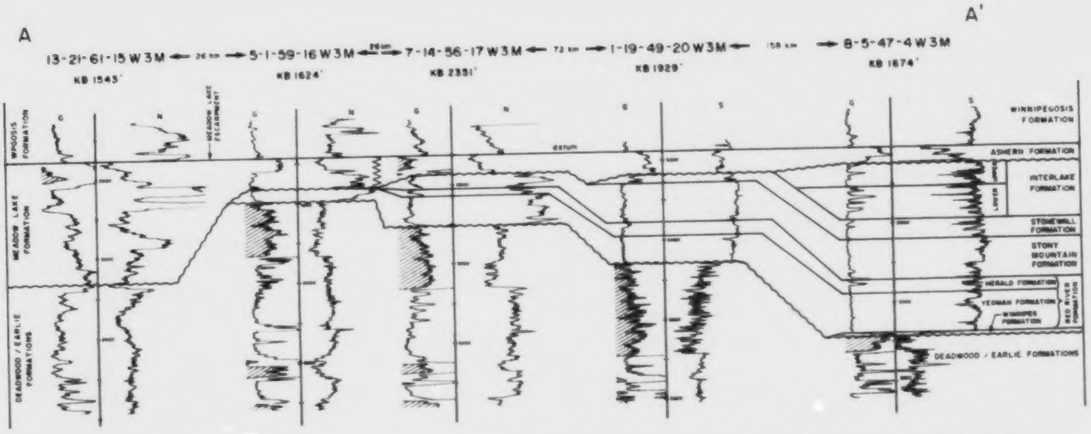

A
A'
13-21-61-15W3M
26 km
5-1-59-16W3M
7-14-56-17W3M
72 km
1-19-49-20W3M
158 km
8-5-47-4W3M
KB 1543'
KB 1624'
KB 2351'
KB 1929'
KB 1674'
G
N
S
MEADOW LAKE ESCARPMENT
datum
WPGOSIS FORMATION
MEADOW LAKE FORMATION
DEADWOOD / EARLIE FORMATIONS
WINNIPEGOSIS FORMATION
ASHERN FORMATION
UPPER
LOWER
INTERLAKE FORMATION
STONEWALL FORMATION
STONY MOUNTAIN FORMATION
HERALD FORMATION
YEOMAN FORMATION
WINNIPEG FORMATION
RED RIVER FORMATION
DEADWOOD / EARLIE FORMATIONS

Figure 2 – Cross section showing progressive truncation of Lower Paleozoic carbonates from south to north. North of the Meadow Lake Escarpment, which formed at the erosional edge of the Red River Formation, Middle Devonian strata (Meadow Lake Fm., Fuzesy, 1980; Meadow Lake Beds and Ashern Formation, van Hees, 1958) infill the erosional low on the Deadwood/Earlie Formations. Location of the cross section is shown in Figure 1. Logs used are gamma (G) and neutron (N) or sonic (S). Datum is the top of the Ashern Formation..

Table 1 - Well data. Well location, kelly bushing elevation, and depth of tops of the Ashern Formation, Meadow Lake Beds, Upper Interlake unit, Lower Interlake unit, Stonewall Formation, Stony Mountain Formation, Red River Formation, Winnipeg Formation, Deadwood/Earlie Formations, and Precambrian in metres. A dash indicates that a unit is not present; a blank space indicates no data are available because well is not deep enough.

WELL LOCATION	K.B.	ASH TOP	MLB TOP	U.INT TOP	L.INT TOP	STW TOP	STM TOP	RR TOP	WPG TOP	DWD TOP	PC TOP
02-05-61-24W2	524.6	---	---	---	---	235.6	244.4	275.2	311.5	319.4	537.4
08-15-64-24W2	504.7	---	---	---	---	---	---	158.5	170.7	204.2	384.7
07-26-51-25W2	479.5	522.4	---	529.1	541.0	568.1	582.2	609.6	654.7	671.8	882.7
16-07-55-25W2	521.8	432.5	---	---	437.4	463.6	478.5	509.3	549.9	555.3	793.4
03-04-59-25W2	507.2	288.6	---	---	---	296.6	309.1	339.5	380.1	386.8	
05-22-62-26W2	589.5	268.8	---	---	---	---	273.1	294.4	330.4	374.3	556.0
04-15-56-27W2	558.1	442.6	---	---	451.7	459.3	476.4	506.3	544.4	552.6	810.2
03-18-63-01W3	648.3	---	---	---	---	---	---	372.2	378.0	433.1	640.4
16-26-47-02W3	503.5	730.3	---	741.6							
13-19-51-02W3	509.6	591.9	---	598.0	600.5	630.3	650.1	675.7	714.1	718.7	1007.1
08-15-52-02W3	539.8	585.2	---	591.6	597.4	622.7	637.6	667.2	705.9	709.9	990.0
08-08-64-02W3	635.8	474.6	491.6	---	---	---	---	---	---	577.6	610.5
08-05-47-04W3	510.2	794.3	---	806.5	824.5	849.8	865.0	896.1	938.5	940.3	
08-03-48-05W3	512.7	762.9	---	770.2	789.7	810.8	827.2	856.8			
14-31-53-05W3	512.1	549.6	---	---	556.9	570.0	585.2	612.6	646.8	648.3	
01-36-63-05W3	557.8	459.3	468.8	---	---	---	---	---	---	548.0	581.9
05-10-55-07W3	498.7	508.4	---	---	---	518.8	535.8	563.3	595.9	597.4	
12-35-58-07W3	505.7	382.2	---	---	---	---	388.0	415.4	444.4	445.9	
09-21-63-08W3	524.9	492.6	503.8	---	---	---	---	---	---	589.5	620.3
07-05-51-09W3	642.2	826.6	---	---	834.2	846.7	865.9	898.6	931.5	933.3	
02-01-58-09W3	490.1	420.6	---	---	---	---	429.2	453.2	485.9	489.2	842.8
04-31-55-10W3	596.5	628.5	---	---	---	637.6	646.8	672.4	702.6	705.6	
02-16-60-10W3	485.2	383.1	392.0	---	---	---	---	---	414.8	416.4	775.7
16-21-61-10W3	499.0	427.3	438.0	---	---	---	---	---	---	467.0	
13-18-65-11W3	491.0	495.3	507.8	---	---	---	---	---	---	594.4	615.1
13-25-51-12W3	591.6	777.8	---	---	---	788.8					
06-14-58-12W3	549.2	534.3	---	---	---	---	---	548.0	570.3	571.8	
02-02-60-12W3	505.1	468.8	481.6	---	---	---	---	---	---	486.2	
10-20-61-12W3	467.3	511.5	523.6	---	---	---	---	---	---	583.4	
14-34-47-13W3	729.7	1056.7	---	1065.6							
10-16-56-14W3	586.4	671.5	---	---	---	---	687.6	693.1	719.3	721.2	
06-23-58-14W3	548.0	554.1	---	---	---	---	---	564.8	---	596.2	
05-25-57-15W3	565.1	608.1	---	---	---	---	---	620.3			
01-16-60-15W3	482.5	605.6	620.3	---	---	---	---	---	---	671.5	
13-21-61-15W3	470.3	597.4	610.5	---	---	---	---	---	---	688.8	839.7
08-30-64-15W3	476.7	580.3	598.3	---	---	---	---	---	---	708.1	731.2
05-19-54-16W3	730.0	900.1	---	---	---	---	914.4	939.1	---	967.7	1399.0
05-01-59-16W3	495.0	513.6	523.3	---	---	---	---	537.1	---	547.4	970.2
07-14-56-17W3	716.6	830.9	---	---	---	---	845.5	856.8	---	885.4	1318.3
01-33-61-17W3	470.6	601.7	619.4	---	---	---	---	---	---	712.6	885.1
03-27-49-18W3	576.1	910.7	---	---	---	925.1	932.1	963.8	---	1003.7	
16-02-51-18W3	682.1	970.5	---	---	---	985.1	990.0	1021.4	---	1056.4	
07-28-62-18W3	499.0	662.3	685.5	---	---	---	---	---	---	789.4	
10-05-51-19W3	649.8	964.4	---	---	---	981.5					
06-09-53-19W3	681.8	930.6	---	---	---	---	940.9				
12-04-58-19W3	564.8	677.9	691.0	---	---	---	---	---	---	715.1	
08-26-48-20W3	558.1	955.5	---	---	---	972.9	983.3	1017.0	---	1050.6	
01-19-49-20W3	588.0	968.7	---	---	---	986.0	992.4	1022.3	---	1054.3	1511.8
02-11-50-20W3	585.5	929.0	---	---	---	945.8	948.8	983.0	---	1014.7	
06-05-51-20W3	615.4	947.3	---	---	---	---	961.3	993.6	---	1026.6	1481.3
15-10-58-20W3	530.7	724.8	731.5	---	---	---	---	---	---	822.7	1147.6
02-13-60-20W3	520.3	731.8	755.9	---	---	---	---	---	---	814.7	1052.2
07-35-48-21W3	553.2	954.6	---	---	---	969.6	977.2	1007.7	---	1042.4	
04-34-58-21W3	562.1	809.2	840.0	---	---	---	---	---	---	881.5	1184.5
12-34-63-21W3	594.4	766.9	793.1	---	---	---	---	---	---	915.3	
10-23-48-22W3	566.0	992.7	---	---	---	1008.9	1014.4	1046.1	---	1083.3	
10-23-50-22W3	573.0	934.5	---	---	---	---	947.0				
01-25-51-22W3	657.5	989.1	---	---	---	---	1000.4	1034.2	---	1065.3	
08-11-62-22W3	520.6	731.2	762.6	---	---	---	---	---	---	874.8	1051.9
06-25-51-23W3	591.6	936.7	---	---	---	---	945.8	953.4			
12-10-56-23W3	655.0	887.9	905.3	---	---	---	---	---	---	925.4	
06-01-49-24W3	644.0	1081.7	---	---	---	---	1094.8	1122.6	---	1163.4	1646.8
10-09-50-24W3	602.0	1004.9	---	---	---	---	1017.1				
10-07-51-24W3	575.2	967.7	---	---	---	---	978.4	1001.3	---	1039.4	1533.1
06-05-52-24W3	654.9	1016.5	---	---	---	---	1030.8				
01-16-53-24W3	569.1	895.2	---	---	---	---	---	911.7	---	954.9	
10-02-59-24W3	568.8	802.8	833.6	---	---	---	---	---	---	1001.3	
15-13-60-24W3	556.6	753.5	786.1	---	---	---	---	---	---	1007.1	
10-24-53-25W3	634.6	966.8	---	---	---	---	---	986.3	---	1005.2	1518.8
01-25-62-25W3	553.5	748.0	780.3	---	---	---	---	---	---	1056.1	1147.3
10-23-52-26W3	573.9	962.3	---	---	---	---	981.5	987.6	---	1021.4	1522.7
01-25-54-26W3	667.2	1011.0	1033.3	---	---	---	---	1036.0	---	1055.2	1548.4
12-30-49-27W3	646.5	1138.7	---	---	---	---	1149.1	1172.0	---	1205.0	1711.0

micaceous shales and micaceous and glauconitic siltstones (Pugh, 1971).

Preliminary log correlations suggest that similar lithologies are present over much of western Saskatchewan. In the vicinity of the Meadow Lake Escarpment, stratigraphic correlation is less certain. The Deadwood Formation in this area contains coarse-grained siltstones and fine-grained sandstones (Pugh, 1971) thus making it difficult to delineate the Deadwood/Earlie boundary. An additional correlation problem occurs at the base of the clastic sequence directly overlying rocks of Precambrian age. The Basal sandstone unit described by Pugh (1971) has not been defined in Saskatchewan and, therefore, the oldest Cambrian rocks are included in the Deadwood/Earlie sequence.

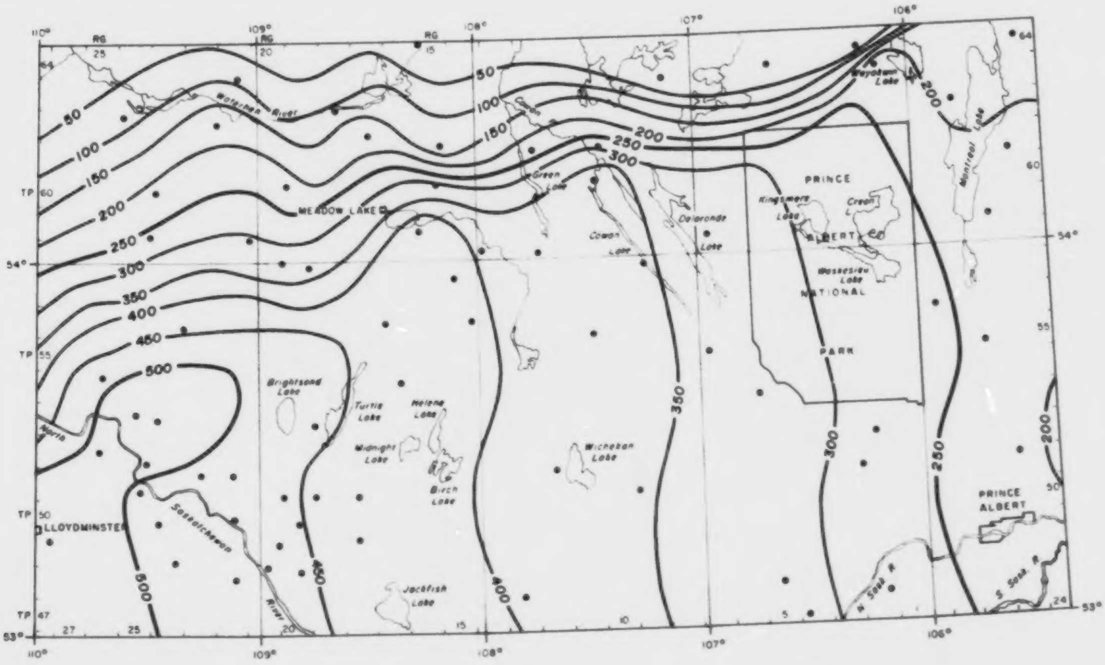
In this study the Deadwood and Earlie Formations have not been differentiated. An isopach map of net thickness of the two formations illustrates both depositional and erosional patterns associated with these strata (Figure 3). Deposition of this sequence took place in the "Lloydminster Embayment", a shallow depression which developed on the Interior Platform of the Western Canada Basin during the Middle Cambrian (van Hees, 1964; Aitken, in press). South of the Meadow Lake Escarpment the distribution of strata reflects deposition within this embayment with maximum thickness (513.6 m) present in 10-24-53-25W3 in the southwest corner of the study area. Two periods of erosion have affected Deadwood/ Earlie strata. The dramatic thinning of Deadwood/Earlie rocks north of the Escarpment is attributed primarily to pre-Devonian erosion. However, pre-Ordovician uplift and erosion on the eastern margin of the basin (van Hees, 1964) also contributed to removal of a portion of this sequence.

b) Winnipeg Formation

The Winnipeg Formation (Middle Ordovician) unconformably overlies the Deadwood Formation in the eastern half of the study area. It is composed predominantly of quartz sandstone with sub-angular to rounded grains ranging from very fine to coarse. The contact with the overlying carbonates of the Red River Formation is described as conformable by some authors (e.g. Vigrass, 1971) and as unconformable by others (e.g. Paterson, 1971; Kendall, 1976). The thin sheet (<3 m) of Winnipeg strata that blankets much of the study area (Figure 4 of Paterson, 1971), is interpreted by Kendall (1976) as the basal sandstone (or arenaceous dolomite) commonly present at the base of the Red River Formation. Maximum thickness (up to 55.1 m) of the Winnipeg Formation in the study area occurs in the northeast corner; the author's correlation of this thick sand unit as part of the Winnipeg Formation is tentative.

c) Herald and Yeoman Formations (Red River Formation)

A thin remnant (16 m) of the Yeoman Formation cored in California Standard Fort Pitt 1-25-54-26W3 is composed primarily of burrowed, mottled and commonly



110°
109°
108°
107°
106°
RG 25
RG 20
RG 15
TP 64
TP 60
TP 55
TP 50
TP 47
54°
53°
27
25
20
15
10
5
24
60
55
50
64
50
100
150
200
250
300
350
400
450
500
Waterhen River
Green Lake
Cowan
MEADOW LAKE
Cowan Lake
Dolorande Lake
Doré Lake
PRINCE ALBERT NATIONAL PARK
Kingsmere Lake
Crean L.
Waskesiu Lake
Montreal Lake
Brightsand Lake
Turtle Lake
Helene Lake
Midnight Lake
Birch Lake
Wichekan Lake
Jackfish Lake
LLOYDMINSTER
Saskatchewan River
N. Sask. R.
S. Sask. R.
PRINCE ALBERT

Figure 3 – Isopach map of undifferentiated Deadwood and Earlie Formations. Contour interval is 50 m.

nodular dolomite. Geophysical log response and samples suggest that this lithology is typical of the Yeoman throughout the study area. The burrowed and mottled nature is characteristic of this unit throughout the Williston Basin (Kendall, 1976, 1985; Haidl, 1988). In the Fort Pitt core (1-25-54-26W3) the dolomite sequence contains anomalous abundant lenses and irregular beds of reddish-brown dolomitic shale and anhydrite over a 3.5 m interval approximately 5 m below the top of the Yeoman. The contacts between the dolomite and the shale clearly indicate infiltration by the shale of the overlying Ashern Formation into fractures and solution cavities developed in the carbonate during the pre-Devonian erosional period. Anhydrite was probably precipitated in cavities in the Yeoman Formation at the same time as it formed in the Ashern Formation.

The Herald Formation has not been cored in the study area but geophysical log response and samples indicate that it is composed of microcystalline dolomite with interbeds of argillaceous dolomite. The contact between the Herald Formation and the overlying Stony Mountain Formation is placed at the base of a marker bed characterized by a marked deflection to the right (higher values) on gamma ray logs. This bed is composed of argillaceous dolomite, with interbeds of arenaceous dolomite. The presence of multiple argillaceous beds with similar log response within the Herald Formation and within the lower portion of the Stony Mountain Formation often makes correlation of this contact difficult (Figure 2).

In this study, the Yeoman and Herald Formations have been mapped as one unit. The contact between the two formations is described as gradational and is difficult to pick even in areas with good well and core control (Kendall, 1976; Haidl, 1988). For this reason the Herald/Yeoman contact has not been picked for the purpose of regional mapping. This undifferentiated Herald/Yeoman unit is equivalent to the Red River Formation in adjacent areas of the Williston Basin. In the study area, total thickness of Herald/Yeoman strata ranges from 45.1 m in 7-26-51-25W2 to zero along the erosional edge (Figure 1). Depositional thicknesses (where penetrated) range from the maximum of 45.1 m in 7-26-51-25W2 to a minimum of 28.1 m in 10-16-56-14W3.

d) Stony Mountain Formation

The subcrop of the Stony Mountain Formation also follows a northeast-southwest trend, roughly parallel to the Meadow Lake Escarpment (Figure 1). Data from wells which penetrate the depositional thickness of these strata indicate that maximum thickness of Stony Mountain strata (up to 34.2 m) occurs in the southwest portion of the map area. The two wells (13-19-51-2W3 and 4-31-55-10W3) with minimum thickness (25.6 m) are located along a line running northwest from the city of Prince Albert. In 13-19-51-2W3, the decreased thickness of the Stony Mountain coincides with a thick Stonewall interval. The gamma ray log over the Stonewall/Stony Mountain sequence in this well indicates a number of anomalously high gamma responses. However, no significant increase in argillaceous content is apparent in drill cuttings.

No cores were taken from this formation but samples and geophysical log response indicate that this interval is composed of burrowed mottled dolomite with minor interbeds of argillaceous dolomite, similar to the lithologies observed in Stony Mountain cores from the Cumberland Lake area in east-central Saskatchewan (Haidl, 1988).

The upper contact of the Stony Mountain Formation is placed at the base of a thin argillaceous dolomite bed (commonly with quartz grains) which, where well-developed, has a characteristic high gamma ray log reading. However, in several wells this marker bed is not well-defined, making accurate correlation of the Stonewall/Stony Mountain boundary difficult (Figure 2).

e) Stonewall Formation

In west-central Saskatchewan the Stonewall Formation is composed of microcrystalline, in places fossiliferous, dolomite and cryptocrystalline dolomite. Prominent marker beds are present at the base, in the middle ("t" horizon), and at the top of the formation. The marker beds consist of argillaceous dolomite with interlaminations of dolomitic shale. Quartz grains are commonly observed in samples, usually as scattered grains in argillaceous dolomite, but also as sandstone samples.

The entire Stonewall Formation is preserved in the southeastern portion of the study area where it ranges in thickness from 14.1 m in 7-26-51-25W2 to 19.8 m in 13-19-51-2W3. The subcrop of the Stonewall Formation is illustrated in Figure 1.

f) Interlake Formation

Rocks of the Interlake Formation are preserved in the southeastern portion of the study area. The erosional edge follows a northeast-southwest trend, parallel to the subcrops of other Lower Paleozoic carbonate units (Figure 1).

In Saskatchewan, the Interlake is subdivided into two informal stratigraphic units, Lower and Upper Interlake (Haidl, 1987). The Lower Interlake contains several well-defined marker beds, characterized by a high gamma ray log response, while there is a paucity of such beds in the Upper Interlake. In the study area, fossil fragments, coated grains, and microcrystalline,commonly laminated, dolomite observed in samples all suggest that the lithologic sequence is similar to that observed in cores in east-central Saskatchewan (Haidl, 1988). Samples and log response indicate the occurrence of a number of marker beds composed of argillaceous dolomite with interbeds of dolomitic shale, arenaceous dolomite and minor sandstone.

The basal metre of the Lower Interlake is cored in 11-7-58-21W2, a well just east of the study area. The cored interval consists of a dolomitized coral stromatoporoid(?) floatstone, a lithology characteristic of the basal Lower Interlake in the Cumberland Lake area (Haidl, 1988).

The full depositional thickness of the Lower Interlake unit is penetrated in only five wells where values range from 25.3 m to 29.8 m (Table 1). The erosional remnant of the Upper Interlake in these wells has a maximum thickness of 19.5 m in 8-3-48-5W3.

3. Structure

Structure contours on the top of the Precambrian basement define a homocline which dips to the southwest at approximately 4.5 m per kilometre (Figure 4). No major anomalies are observed on this surface in the map area and present well control is insufficent to define minor structures.

The map of structure contours on the top of Deadwood/Earlie Formations (Figure 5) illustrates strata in the southern portion of the study area dipping to the south-southwest at approximately 4.5 m per kilometre. Along the Meadow Lake Escarpment, erosional relief on these strata disrupts the regional trend. Here contours define a west-southwest trending "nose", roughly parallel to the Escarpment. A similar pattern is defined by contours on the top of the sub-Devonian unconformity (Figure 3 of Buller, 1958).

The principal reason for the trend of the Escarpment is not clear. There appears to be no evidence of significant faulting on the present-day Precambrian surface (Figure 4). There has been speculation that the Escarpment coincides with basement faulting which may have had both vertical and lateral movements (van Hees, 1958, 1964). D.M. Kent (pers. comm.) speculates that this feature, particularly at its northeast extremity, may be associated with an extension of the Stanley Fault (Figure 1 of Padgham, 1968).

4. Further work

This study was originally undertaken as a regional mapping project based primarily on geophysical logs. More detailed work is required to fully understand depositional and erosional features and their relationship to such factors as eustatic sea level changes and basement tectonics.

a) Stratigraphic correlation north of the Meadow Lake Escarpment

Interpretation of depositional and erosional features in this area requires detailed stratigraphic correlation based on comprehensive knowledge of the lithologies of the various formations. The basal clastic sequence requires further study in order to differentiate the "Basal sandstone", and the Deadwood, Earlie and Winnipeg Formations. The complex lithologies of the Meadow Lake Formation must also be mapped in detail in order that a sandy facies of the Meadow Lake Formation can more readily be distinguished from the underlying Deadwood or Earlie Formations, or a Meadow Lake dolomite from a remnant of the Red River Formation.

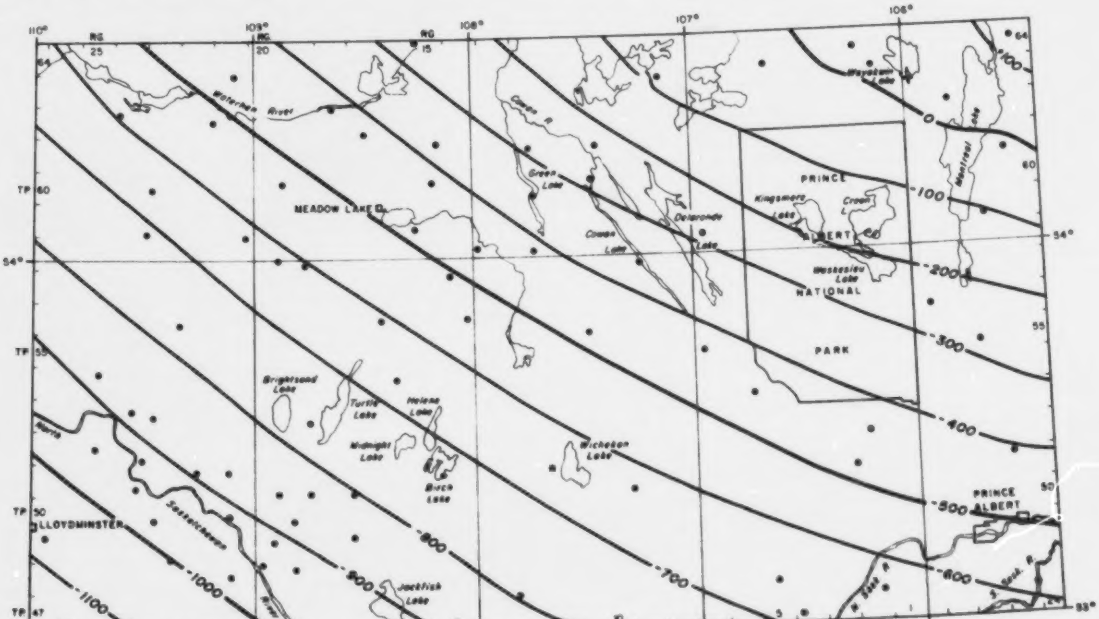

110°
109°
108°
107°
106°
RG 25
RG 20
RG 15
64
TP 60
54°
TP 55
TP 50
TP 47
53°
Waterhen River
MEADOW LAKE
Green Lake
Cowan Lake
Delaronde Lake
PRINCE ALBERT NATIONAL PARK
Kingsmere Lake
Crean L.
Waskesiu Lake
Montreal Lake
Brightsand Lake
Turtle Lake
Helene Lake
Midnight Lake
Birch Lake
Witchekan Lake
Jackfish Lake
LLOYDMINSTER
Saskatchewan River
PRINCE ALBERT
N. Sask. R.
S. Sask. R.
100
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
-1100

Figure 4 – Structure contours on the top of the Precambrian. Contour interval is 100 m; datum is mean sea level.

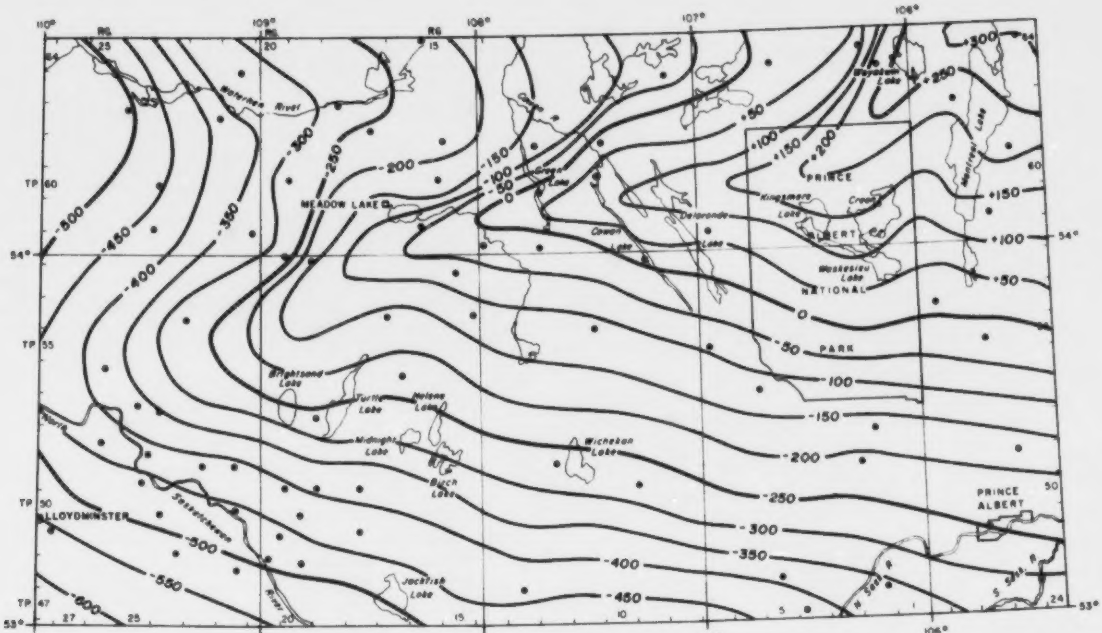

110°
109°
108°
107°
106°
R6
25
20
15
TP 60
54°
TP 55
TP 50
TP 47
53°
27
10
5
24
MEADOW LAKE
Waterhen River
PRINCE ALBERT NATIONAL PARK
Kingsmere Lake
Crean
Delaronde Lake
Cowan Lake
Waskesiu Lake
Montreal Lake
Brightsand Lake
Turtle Lake
Helene Lake
Midnight Lake
Birch Lake
Wicheken Lake
Jackfish Lake
LLOYDMINSTER
Saskatchewan River
PRINCE ALBERT
N. Sask. R.
S. Sask. R.
-500
-450
-400
-350
-300
-250
-200
-150
-100
-50
0
+50
+100
+150
+200
+250
+300
-50
100
-150
-200
-250
-300
-350
-400
-450
-500
-550
-600

Figure 5 - Structure contours on the top of undifferentiated Deadwood/Earlie Formations. Contour interval is 50 m; datum is mean sea level.

b) Depositional Trends

Analysis of depositional trends requires that the area of study be extended away from the erosional edges of the various formations. More detailed lithologic data must be acquired to improve understanding of depositional sequences within both the clastic and carbonate units. Integration of these data with geophysical data may enhance understanding of the relationship of depositional and erosional features to basement tectonics.

One depositional trend observed in this study warrants more detailed analysis. The southeast-northwest trending depositional thin in the Stony Mountain Formation to the northwest of Prince Albert possibly extends to the southeast to Township 37, Range 9W2 where a similar feature exists (Figure 19 of Kendall, 1976). It is of interest to note that the Sturgeon Lake kimberlite discovery (Twp. 51, Rge. 1W3) lies along this trend.

5. References

Aitken, J.D. (in press): The Sauk Sequence - Cambrian to Lower Ordovician: the birth of a Lower Paleozoic passive margin; *in* Ricketts, B. (ed.), Basin Analysis - the Western Canada Sedimentary Basin; Can. Soc. Petrol. Geol., Spec. Publ. 30.

Buller, J.V. (1958): On the Sub-Ashern stratigraphy of an area in the northwestern part of the sedimentary basin of Saskatchewan; Oil in Canada, v10, No. 23, p34-44.

Fuzesy, L.M. (1980): Geology of the Deadwood (Cambrian), Meadow Lake and Winnipegosis (Devonian) Formations in west-central Saskatchewan; Sask. Miner. Resour., Rep. 180, 64p.

Fyson, W.K. (1961): Deadwood and Winnipeg stratigraphy in southwestern Saskatchewan; Sask. Miner. Resour., Rep. 64, 37p.

Haidl, F.M. (1987): Stratigraphic and lithologic relationships, Interlake Formation (Silurian), southern Saskatchewan; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p187-193.

__________ (1988): Lithology and stratigraphy of lower Paleozoic strata: new information from cores in the Cumberland Lake area, east-central Saskatchewan; *In* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p202-210.

Kendall, A.C. (1976): The Ordovician carbonate succession (Bighorn Group) of southeastern Saskatchewan; Sask. Miner. Resour., Rep. 180, 185p.

__________ (1985): Depositional and diagenetic alterations of Yeoman (Lower Red River) carbonates from Harding Co., South Dakota; *in* Longman, M.W., Shanley, K.W., Lindsay, R.F. and Eby, D.E. (eds), Rocky Mountain Carbonate Reservoirs - A Core Workshop; Soc. Econ. Paleon. Mineral., p95-124.

Lefever, R.D., Thompson, S.C. and Anderson, D.B. (1987): Earliest Paleozoic history of the Williston Basin in North Dakota; *in* Fifth International Williston Basin Symposium; Sask. Geol. Soc./N. Dak. Geol. Soc., Spec. Publ. 9, p22-36.

Osadetz, K.G. and Haidl, F.M. (in press): Tippecanoe Sequence: Middle Ordovician to Lowest Devonian vestiges of a great epeiric sea; *in* Ricketts, B. (ed.), Basin Analysis – the Western Canada Sedimentary Basin; Can. Soc. Petrol. Geol., Spec. Publ. 30.

Padgham, W.A. (1968): The geology of the Deschambault Lake District; Sask. Dep. Miner. Resour., Rep. 114, 92p.

Paterson, D.F. (1971): The stratigraphy of the Winnipeg Formation (Ordovician) of Saskatchewan; Sask. Dep. Miner. Resour., Rep. 140, 57p.

________ (1988): Review of regional stratigraphic relationships of the Winnipeg Group (Ordovician), the Deadwood Formation (Cambro-Ordovician) and underlying strata in Saskatchewan; *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p224-225.

Pugh, D.C. (1971): Subsurface Cambrian stratigraphy in southern and central Alberta; Geol. Surv. Can., Pap. 70-10, 33p.

Sloss, L.L. (1963): Sequences in the cratonic interior of North America; Bull. Geol. Soc. Am., v74, p93-114.

van Hees, H. (1956): The Elk Point Group; Jour. Alta. Soc. Petrol. Geol., v4, No.2, 29-30p.

________ (1958): The Meadow Lake Escarpment – its regional significance to Lower Palaeozoic stratigraphy; *in* Second International Williston Basin Symposium; N. Dak. Geol. Soc./Sask. Geol. Soc., p70-78.

________ (1964): Cambrian; *in* McCrossan, R.G. and Glaister, R.P. (eds.), Geological History of Western Canada; Alta. Soc. Petrol. Geol., Calgary, p20-28.

Vigrass, L.W. (1971): Depositonal framework of the Winnipeg Formation in Manitoba and eastern Saskatchewan; Geol. Assoc. Can., Spec. Pap. 9, p225-234.

Palynology of the Shaunavon and Gravelbourg Formations of Southern Saskatchewan

L.K. Kreis

Kreis, L.K. (1989): Palynology of the Shaunavon and Gravelbourg Formations of southern Saskatchewan, *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

This paper reports preliminary examinations made in 1989 of palynological data from Jurassic strata in southern Saskatchewan. Sample preparation and identification were conducted by Dr. E.M.V. Nambudiri, with the Energy Research Unit, University of Regina. The author acknowledges Dr. Nambudiri's invaluable contribution towards an interpretation of the palynomorphs present.

The investigation is part of an ongoing study by the author entitled, "Stratigraphy of the Jurassic System in the Wapella-Moosomin area, southeastern Saskatchewan" ("Study Area" in Figure 1a, in pocket). The major goals of the study are 1) to establish the stratigraphic relationships between the Jurassic section in the Wapella-Moosomin area of southeastern Saskatchewan and the type area for the Jurassic in southwestern Saskatchewan (Figures 1a and 1b, in pocket), and 2) to provide an interpretation of the depositional history for the Jurassic System in the Wapella-Moosomin area. A more detailed discussion of the stratigraphic and ecological implications of the palynological results will be published later.

1. Previous Work

Previous palynological investigations of the Jurassic strata in Saskatchewan are limited to reports by Pocock (1970 and 1972). Pocock (1972) established a framework of palynomorph assemblages for the major stratigraphic units defined by Milner and Thomas (1954) for the Jurassic section in southwestern Saskatchewan, namely (oldest to youngest) the Watrous, Gravelbourg and Shaunavon Formations and the Vanguard Group.

Numerous depositional breaks and lithofacies changes within the Shaunavon Formation and upper member of the Gravelbourg Formation in southeastern Saskatchewan make correlation with strata in the type area of southwestern Saskatchewan very difficult when attempted on the basis of lithological and geophysical log characteristics (Kreis, 1988). Kreis invoked an arbitrary lithofacies boundary to separate the Shaunavon Formation and upper member of the Gravelbourg Formation of southwestern Saskatchewan from the equivalent strata in southeastern Saskatchewan, which he named, the Red Jacket Formation (Figures 1a and 1b). He subdivided the Red Jacket Formation into three members (O-Y): Rocanville Member, Moosomin Member and Burrows Member. For a more detailed discussion of nomenclature see Kreis (1988).

2. Palynological Results

The focus of this investigation is on the palynology of the Shaunavon and Gravelbourg Formations of southwestern Saskatchewan, and the Red Jacket Formation of the southeast. Although most samples are from the Wapella-Moosomin area, the results have aided stratigraphic correlations in both areas. To supplement Pocock's (1970, 1972) work, 52 samples from the Shaunavon and Gravelbourg Formations were taken from 20 wells across southern Saskatchewan (Figures 1a and 1b, in pocket). Only 38 samples from 18 wells proved to have sufficiently preserved, identifiable palynomorph specimens. A summary of typical palynomorph assemblages for the upper and lower members of the Gravelbourg Formation, upper and lower members of the Shaunavon Formation, Rocanville Member, Moosomin Member (units A and B) and Burrows Member (units A and B) is given in Table 1.

a) Lower Gravelbourg Member

Only three of seven samples taken from the lower Gravelbourg member yielded specimens of sufficient preservation to warrant examination, two from unit A and one from the overlying unit B. Poor preservation of palynomorphs in the latter sample likely resulted from slow deposition in a high pH environment; conditions considered by Traverse (1988) to be corrosive to palynomorphs. The presence of abundant organic-walled microforaminifera in unit B supports Pocock's (1972) interpretation of a marine depositional environment. Microforaminifera were not found in Unit A, but the presence of acritarchs like *Leiosphaeridia staplinii* and *Leiosphaeridia tangentensis* suggest a marine influence for this unit as well. This compliments the interpretation that the dolomitic and locally algally-laminated limestones of unit A were deposited in a restricted shallow marine environment; whereas the calcareous mudstones and bioclastic limestones of unit B are interpreted to have been deposited in a more open marine environment.

The palynomorph assemblage in the lower member of the Gravelbourg Formation in the present study is similar to that found in the same member by Pocock (1972). *Leiosphaeridia staplinii*, *Leiosphaeridia tangentensis*, *Murospora minor*, and species of *Concavissimisporites* are index species from unit A in this study, and *Lycopodiumsporites pseudoannotinus* and species of *Leiosphaeridia* are the index species from unit B. All of these palynomorphs are also index species for the

Table 1 - Typical Palynomorph Assemblages

	STRATIGRAPHIC UNITS									
	LGA	LGB	UG	LS1	US	RM	MMA	MMB	BMA	BMB
PALYNOMORPHS										
Terrestrial Species										
Baculatisporites truncatus	-	-	-	X	-	-	-	-	-	-
Bennettiteaepollenites canadensis	-	-	X	-	-	-	-	X	-	-
Bennettiteaepollenites lucifer	-	-	-	-	X	-	X	-	-	-
Bennettiteaepollenites shaunavonensis	-	-	-	X	-	-	-	X	-	-
Calamospora mesozoica	-	-	X	X	-	X	-	-	X	-
Callialasporites trilobatus	X	-	-	X	-	-	-	-	-	-
Ceratosporites spinosus	-	-	-	-	X	-	-	-	-	-
Cerebropollenites macroverrucocus	-	-	X	-	-	-	-	X	-	-
Cerebropollenites mesozoicus	-	-	-	-	-	X	-	-	-	-
Cerebropollenites sp.	-	-	-	-	X	-	-	-	-	-
Classopollis classoides	X	-	-	-	-	-	-	X	-	-
Classopollis itunensis	-	-	X	-	-	X	-	X	-	-
Concavissimisporites delcourtii	-	-	-	-	-	-	-	X	-	-
Concavissimisporites southeyensis	-	-	X	X	-	X	-	-	-	-
Concavissimisporites subgranulatus	-	-	-	-	-	-	-	-	X	-
Concavissimisporites sp.	X	-	-	-	-	-	-	-	-	-
Corrugatisporites amplectiformis	-	-	-	-	-	X	-	-	-	-
Corrugatisporites wallii	-	-	-	-	-	X	-	X	-	-
Cyathidites minor	-	-	X	-	-	X	-	-	-	-
Cycadopites jansonii	-	-	-	-	X	-	-	-	-	-
Cycadopites minimus	-	-	-	-	X	-	-	X	X	-
Deltoidospora harrisii	-	-	X	-	X	-	-	X	-	-
Deltoidospora minor	-	-	-	-	X	-	-	X	X	-
Dictyophyllidites sp.	-	-	-	-	-	-	X	-	-	-
Dictyotriletes crateris	-	-	X	X	-	-	-	-	-	-
Distanulisporites verrucosus	-	-	-	X	-	-	-	-	-	-
Eucommiidites troedsonii	-	-	-	-	-	X	-	-	-	-
Exesipollenites scabratus	-	X	-	-	-	-	-	-	-	-
Exesipollenites tumulus	-	-	-	-	-	-	-	-	X	-
Gleicheniidites delicatus	-	-	-	-	-	-	-	X	-	-
Gleicheniidites granulatus	-	-	-	-	X	-	-	-	-	-
Gleicheniidites minor	-	-	-	-	X	-	-	-	-	-
Gleicheniidites nilssonii	-	-	X	-	-	-	-	-	-	-
Gleicheniidites rousei	-	-	-	-	X	-	-	-	-	-
Harrisispora equiexinus	-	-	-	-	-	-	-	-	X	-
Inaperturopollenites turbatus	-	-	X	-	X	-	X	-	-	-
Lycopodiumsporites bacculatus	-	-	-	-	X	-	-	-	-	-
Lycopodiumsporites dejerseyi	X	-	-	-	-	-	-	-	-	-
Lycopodiumsporites pseudoannotinus	-	X	-	-	-	-	-	-	-	-
Manumia verrucata	-	-	-	-	-	-	-	-	X	-
Murospora bicollateralis	-	-	X	-	X	-	-	-	-	-
Murospora minor	X	-	-	-	-	-	-	-	-	-
Murospora sp.	X	-	-	-	-	-	-	-	-	-
Ovalipollis canadensis	-	-	X	-	-	-	-	-	-	-
Pityosporites divulgatus	-	X	X	-	-	-	-	-	-	-
Platysaccus lopsinensis	-	-	-	-	-	-	X	-	-	-
Podocarpidites langii	-	-	-	-	-	-	X	-	-	-
Podocarpidites wapellaensis	-	-	X	-	-	X	-	-	-	-
Protoconiferus microsaccus	-	-	-	X	-	-	-	-	-	-
Protopicea exilioides	-	X	X	-	-	X	-	-	-	-
Reticulatisporites jurassicus	-	-	-	X	-	-	-	-	-	-
Reticulatisporites sp.	-	-	-	-	-	X	-	-	-	-
Triangulopsis discoidalis	-	-	X	-	-	X	-	-	-	-
Marine Species										
organic-walled foraminifera	-	X	-	-	-	-	-	X	-	-
dinoflagellates (indeterminate)	-	-	-	X	-	-	-	-	-	-
Chytroeisphaeridia variabilis	-	-	-	-	X	-	-	-	-	-
Comasphaeridium sp.A	-	-	-	-	-	-	X	-	-	-
Cymatiosphaera sp.	-	-	-	-	-	-	-	-	X	-
Gonyaulacysta jurassica	-	-	-	-	-	-	-	-	X	-
Gonyaulacysta ornata	-	-	-	-	-	-	-	-	X	-
Gonyaulax canadensis	-	-	-	-	X	-	-	-	-	-
Leiofusa deunffii	-	-	-	-	X	-	-	-	X	-
Leiosphaeridia hyalina	-	-	-	-	-	-	X	-	-	-
Leiosphaeridia stapiinii	X	-	-	X	-	-	-	X	X	-
Leiosphaeridia tangentensis	X	X	-	X	-	-	-	X	-	-
Leiosphaeridia sp.	-	X	-	-	-	-	-	-	-	-
Rugidinium ornatum	-	-	-	-	-	-	-	X	-	-
Rugidinium undulatum	-	-	X	-	-	-	-	-	-	-
Rugidinium sp.	-	-	-	-	-	-	-	X	-	-
Solisphaeridium deflandrei	-	-	-	-	-	-	-	X	-	-
Tasmanites clairmontensis	-	-	-	-	X	-	-	-	-	-
Tasmanites suevicus	-	-	-	X	-	X	-	-	-	-
Tasmanites yarboensis	-	-	X	-	-	-	-	-	-	-

Abbreviations:

LGA - Lower Gravelbourg, Unit A
LGB - Lower Gravelbourg, Unit B
UG - Upper Gravelbourg
LS1 - Lower Shaunavon, Unit 1
US - Upper Shaunavon
RM - Rocanville Member
MMA - Moosomin Member, Unit A
MMB - Moosomin Member, Unit B
BMA - Burrows Member, Unit A
BMB - Burrows Member, Unit B

lower member of the Gravelbourg Formation described by Pocock (1972).

Classopollis spores, reported "in abundance" by Pocock (1972) in the lower member of the Gravelbourg Formation are rarer in unit A, and absent in unit B of this report. However, in only one well did unit B yield identifiable palynomorphs, and these were poorly preserved.

Since Pocock (1972) does not indicate the well location or depths of recovery for most of his samples, it is difficult to determine the southwestern stratigraphic equivalents of units A and B. Unit A appears to be more similar than unit B to the lower member of the Gravelbourg described by Pocock, having a greater number of the palynomorph index species. On the other hand, unit B was found to be marine, and Pocock (1972) does not recognize a marine sequence in the upper Gravelbourg. Unit B, therefore, is taken to be the uppermost unit of the lower member of the Gravelbourg.

Unit B is not present in the type section of the Gravelbourg Formation (well number 1 in Figure 1b), instead, the upper Gravelbourg rests unconformably on what appears to be unit A of the lower Gravelbourg. East of this well, unit B overlies unit A all the way to the Wapella-Moosomin area (Figure 1b). A well-defined unconformity which separates these units in both the southeast and southwest, exhibits weathered dolomite, with vugs filled by secondary quartz and bluish grey chalcedonic chert (Kreis, 1988).

The contact between the upper and lower member of the Gravelbourg Formation is sharp, but evidence of erosion and weathering is lacking, arguing against a clear unconformity. This contact more probably represents a paraconformity.

b) Upper Gravelbourg Member

Seven samples taken from the upper member of the Gravelbourg have a combined palynomorph assemblage including: *Bennettiteaepollenites canadensis*, *Calamospora mesozoica*, *Cerebropollenites macroverrucosus*, *Concavissimisporites southeyensis*, *Gleicheniidites nilssonii*, *Inaperturopollenites turbatus*, *Lycopodiumsporites pseudoannotinus*, *Pityosporites divulgatus* and *Protopicea exilioides*, that is quite similar to Pocock's (1972). Pocock noted an abrupt change in character of the palynology of the assemblages at the boundary between the upper and lower members of the Gravelbourg Formation, indicating an abrupt change in the depositional environment. He also felt that this change was indicative of an unconformity at this contact. Pocock suggested that the lack of marine palynomorphs in the upper member indicated a lacustrine depositional environment.

While major components of the terrestrial palynological assemblage in both studies are similar, the occurrence of species of *Leiosphaeridia*, *Rugidinium undulatum* and of *Tasmanites* in the upper Gravelbourg in the present study suggests some marine influence. Taylor (1981) suggests a marine origin for the genera *Tasmanites*. Thus a coastal marine environment is envisaged for the upper member of the Gravelbourg Formation.

c) Lower Shaunavon Member

Palynomorph recovery from four samples from the lower member of the Shaunavon Formation, was rather poor. A particularily poor sample (1-17-20-23W2, 2465-2466 ft) was mounted as a epoxy pellet, examined under ultraviolet light, and found to contain abundant zoned dolomite rhomboids. Also present were pyritized microforams, scattered inertinite and several acritarchs of the *Veryhachium* type.

The lower Shaunavon samples come from what appears to be a transitional unit between the upper member of the Gravelbourg Formation and the lower member of the Shaunavon Formation. This lithostratigraphic zone has also been recognized by Christopher (1989, pers. comm.) and is designated as unit 1 of the lower Shaunavon on the cross section in Figure 1b. It occurs in well number 6 (i.e. 14-29-7-29W2) of the cross section, but is difficult to recognize east of the arbitrary lithofacies boundary (Figures 1a and 1b, in pocket).

Several palynomorph species found in both this study and Pocock's (1972) are *Baculatisporites truncatus*, *Classopollis classoides*, *Tasmanites suevicus* and *Protoconiferus microsaccus*, but the abundant dinoflagellates reported by Pocock (1972) are not apparent in the present samples. Only scarce specimens of the genera *Tasmanites* and *Leiosphaeridia* and a few unidentified dinoflagellates are found. The relative scarcity of dinoflagellates in unit 1 of the lower member of the Shaunavon suggests that the lower Shaunavon coastline was nearby (probably to the northeast), and may also be attributed to slow deposition in a high pH environment.

d) Upper Shaunavon Member

The palynomorph assemblage found in four samples of the upper member of the Shaunavon Formation differs significantly from Pocock (1972); the only common palynomorph is *Chytroeisphaeridia variabilis*. Sedimentological evidence suggests that shallow near-shore sedimentation prevailed during most of upper Shaunavon time, and that broad shifts in the strand-line was common (Christopher, 1964). This shifting of environments may have caused the differences in the palynological assemblages, observed between Pocock's (1972) and the present study.

The palynological assemblage for the upper member of the Shaunavon is only similar to Pocock's with respect to the relative abundance of terrestrial species, but several marine species were identified that support a near-shore depositional environment (Table 1).

e) Rocanville Member

Most of the eight samples taken from the upper half of the Rocanville Member yielded poorly preserved and commonly unidentifiable specimens. Poor preservation of palynomorphs in the oxidized dolomitic and calcareous mudstones of this unit is attributed to slow deposition in a high pH environment (Traverse, 1988). Evidence for subaerial exposure is seen in the oxidized and variegated nature of the mudstones. Subaerial exposure may have led to further corrosion of palynomorphs by bacterial action (*ibid*). Additional lithological and stratigraphic evidence of exposure is cited by Kreis (1988).

One sample taken from a one-metre thick carbonaceous sandy siltstone unit at the base of the Rocanville Member (6-33-14-1W2, 2492 feet) in the Wapella-Moosomin area yielded the palynomorphs *Calamospora mesozoica* and *Protopicea exilioides* which are index species for the upper Gravelbourg described by Pocock (1972). Other palynomorphs found which are index species for both the Rocanville Member and the typical assemblage for the upper member of the Gravelbourg in this study are: *Classopollis itunensis*, *Concavissimisporites southeyensis*, *Cyathidites minor*, and *Podocarpidites wapellaensis*. The presence of these index species supports the idea that some of the lowermost section of the Rocanville Member in the Wapella-Moosomin area may be correlated on lithological and palynological grounds with the upper member of the Gravelbourg Formation, west of the arbitrary lithofacies boundary (Figures 1a and 1b).

The presence of *Calamospora mesozoica*, *Concavissimisporites southeyensis*, *Tasmanites suevicus* and some dinoflagellates (indeterminate) in both the Rocanville Member and the lower member of the Shaunavon supports the argument that these units are stratigraphic equivalents. Thus the Rocanville Member appears to be stratigraphically equivalent to both the lower member of the Shaunavon Formation and the upper member of the Gravelbourg Formation of southwestern Saskatchewan.

f) Moosomin Member

A total of 10 samples, 3 from Unit A and 7 from Unit B, were taken from the Moosomin Member of the Red Jacket Formation in the Wapella-Moosomin area, yielding an abundant and diverse terrestrial palynological assemblage. This suggests that the Moosomin is equivalent to at least part of the upper member of the Shaunavon Formation of southwestern and south-central Saskatchewan which also has an abundant and diverse palynological assemblage.

Although both units A and B contain a diverse and abundant terrestrial assemblage, unit B shows more marine forms than unit A of the Moosomin Member (Table 1). This supports the author's opinion that unit A represents a sequence of estuarine valley-fill sediments and the overlying unit B was deposited in a near-shore depositional setting.

On the basis of geophysical log correlations, the Moosomin Member is most likely equivalent to the upper member of the Shaunavon Formation. A number of the palynomorphs listed as typical for units A and B of the Moosomin Member are found in the upper member of the Shaunavon in this investigation implying that they are stratigraphically equivalent (Table 1). In addition, units A and B have produced a number of palynomorphs which are index species for Pocock's upper member of the Shaunavon, including: *Podocarpidites langii*, *Rugidinium ornatum* and *Solisphaeridium deflandrei*.

Sedimentological evidence for a disconformity between the Rocanville and Moosomin Members is noted by Kreis (1988), possibly suggesting that some of the palynomorphs found in the Moosomin Member may have been derived from the underlying Rocanville. Evidence of extensive reworking, however, was not apparent in samples from this study.

g) Burrows Member

Three samples were taken from the Burrows Member, two from unit A and one from the overlying unit B. The mudstone which comprises unit A is marine and contains over 45 percent dinoflagellates. The presence of abundant *Gonyaulacacean* dinoflagellates suggests these sediments were deposited in open marine conditions (Williams, 1978). The low frequency of terrestrial palynomorphs also supports an open marine interpretation following Traverse (1988) who suggests that spores and pollens are present in virtually all environments but their abundance decreases towards open ocean.

Gonyaulacysta ornata is the only index species of Pocock's (1972) assemblage for the upper member of the Shaunavon Formation found in Unit A of the Burrows. In the present study, *Cycadopites minmus*, *Deltoidospora minor* and *Leiofusa deunffii* all belong to the typical palynomorph assemblages for the upper member of the Shaunavon Formation and unit A of the Burrows Member, suggesting that they are stratigraphic equivalents.

Unhappily, the single sample taken from unit B of the Burrows Member did not yield any palynomorphs.

3. References

Christopher, J.E. (1964): The Middle Jurassic Shaunavon Formation of southwestern Saskatchewan; Sask. Dep. Miner. Resour., Rep. 95, 95p.

Kreis, L.K. (1988): The Red Jacket Formation of southeastern Saskatchewan; *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p211-223.

Milner, R.L. and Thomas, G.E. (1954): Jurassic System in Saskatchewan; *in* Western Canada Sedimentary Basin; Am. Assoc. Pet. Geol., Rutherford Mem. Vol., p250-267.

Pocock, S.A.J. (1970): Palynology of the Jurassic sediments of western Canada; Part 1, Terrestrial Species. Palaeontographica, Abt.B., v130, p12-72.

________ (1972): Palynology of the Jurassic sediments of western Canada; Part 2, Marine Species. Paleontographica, Abt.B., v137: p85-153.

Taylor, T.N. (1981): Paleobotany; McGraw-Hill Book Company, NY, 583p.

Traverse, A. (1988): Paleopalynology; Allen and Unwin, Inc., Mass., 600p.

Williams, G.L. (1978): Dinoflagellates, Acritarchs and Tasmanitids; *in* Haq, B.U. and A. Boersma, (eds.), Introduction to Marine Micropaleontology, Elsevier, NY, p293-326.

Preliminary Report on a Pore Geometry Reservoir Model for the Carbonate Buildups in the Winnipegosis Formation (Devonian) in Southeast Saskatchewan

Melinda Yurkowski

Yurkowski, M. (1989): Preliminary report on a pore geometry reservoir model for the carbonate buildups in the Winnipegosis Formation (Devonian) in southeast Saskatchewan; *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

Devonian Winnipegosis carbonate buildups in southeast Saskatchewan have been a prime target for petroleum exploration since oil was discovered in them by the Home Tableland 8A-22-2-9W2M well in 1986. Over sixty wells have now been drilled into the Winnipegosis, but only twelve have been cased for oil production. These Elk Point Basin carbonate mounds have local variations in production capabilities. The 8A-22-2-9W2M well produced 14766 m^3 of oil prior to January, 1989. In contrast, the 4-1-4-7W2M well, drilled into a different mound, was dry and abandoned. The aim of this pore geometry study is to determine why some buildups produce oil, while others do not, as well as to determine how production is related to lithologies and/or depositional environments.

The study area extends from the Manitoba - U.S. border to Township 10, Range 10W2M (Figure 1). This preliminary report briefly details the geology and stratigraphy of these dolomitized buildups and examines porosity trends on a macroscopic scale.

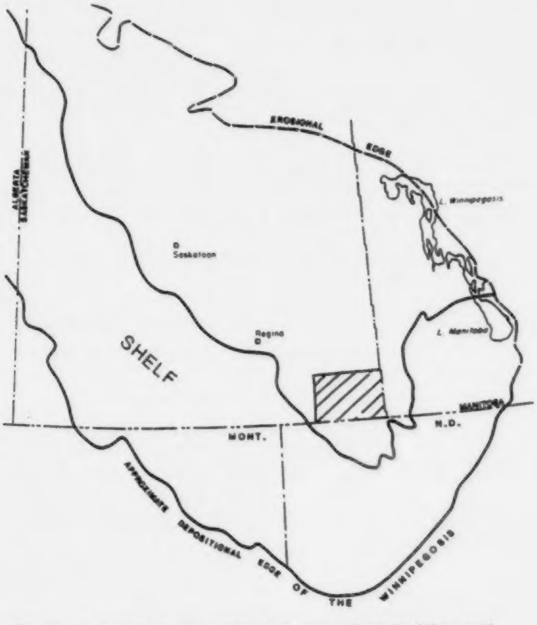

EROSIONAL
EDGE
ALBERTA
SASKATCHEWAN
L. Winnipegosis
Saskatoon
Regina
SHELF
L. Manitoba
MANITOBA
N.D.
MONT.
APPROXIMATE DEPOSITIONAL EDGE OF THE WINNIPEGOSIS

Figure 1 - Location map showing area of study (diagonal ruling) and limits of Winnipegosis Formation.

1. Stratigraphy

The Winnipegosis Formation, which is part of the Middle Devonian Elk Point sequence (Figure 2), is divided into Upper and Lower Members (Reinson and Wardlaw, 1972). The Lower Winnipegosis consists of platform carbonates that rest unconformably on the Lower Elk Point Ashern Formation. The Upper Winnipegosis Member, which constitutes the buildups and reservoir lithologies, and the Ratner Member, which is a bituminous laminite that lies between the buildups and is contemporaneous with them, rest conformably on the Lower Winnipegosis. Both these members are overlain by Whitkow Anhydrite and Whitkow Halite which are in turn overlain by the Upper Prairie Evaporite.

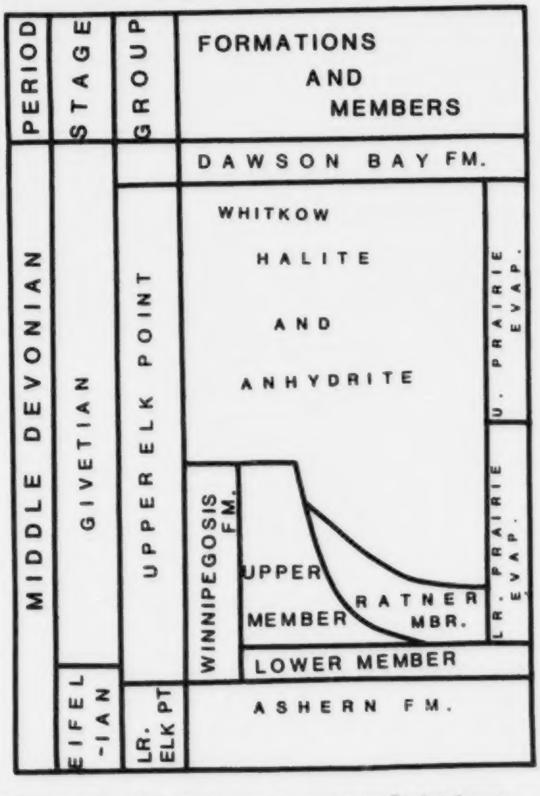

PERIOD
STAGE
GROUP
FORMATIONS AND MEMBERS
MIDDLE DEVONIAN
GIVETIAN
EIFEL-IAN
UPPER ELK POINT
LR. ELK PT
DAWSON BAY FM.
WHITKOW HALITE AND ANHYDRITE
U. PRAIRIE EVAP.
LR. PRAIRIE EVAP.
WINNIPEGOSIS FM.
UPPER MEMBER
RATNER MBR.
LOWER MEMBER
ASHERN FM.

Figure 2 - Devonian stratigraphy in southeast Saskatchewan (adapted by Martindale and MacDonald, 1989)

2. Geological Setting

At the time of Lower Winnipegosis deposition (Late Eifelian), the study area was part of the Elk Point Basin, a northwest-trending basin with the Presqu'ile reef in northern Alberta barring the open sea to the northwest. A marine transgression during late Eifelian times allowed a broad carbonate platform to develop. Later, during Givetian time, differentiation of the basin into shallow shelf and deeper basinal areas (Ehrets and Kissling, 1985) allowed the Upper Winnipegosis to develop as shoals which subsequently were built up high enough into the photic zone to develop a reef framework (Martindale and MacDonald, 1989). A drop in sea-level at the end of Winnipegosis time resulted in the capping of these buildups by a laminated dolomite of subareal origin (*ibid*). The following section is based upon Martindale and MacDonald (1989).

Martindale and MacDonald identified five distinct depositional facies within the mounds of the Tableland area. These facies characterize the majority of Winnipegosis reefs examined to date.

A peloid/Codiacean algal facies comprises the lower part of the buildups and includes foreslope deposits, chaotically bedded mudstones and steeply dipping packstones/grainstones, as well as the peloidal/algal packstones and grainstones of the shoal interior. The grainstones and packstones of the lower part of the buildups exhibit steeply dipping windward margins with early marine cements as the primary stabilizer.

A peloid/algal boundstone facies lies between the grainstone facies and the true reef framework of these buildups. Algal laminations, peloids and the absence of Codiacean algae characterize this facies.

The reef framework exhibits a lateral zonation. Red digitate algal boundstones occupy the shallow high-energy environment of the reef crest, the tabulate coral (*Thamnopora*) framestones lie in the quieter zones, and Chaetetid coral floatstones and boundstones lie on the leeward flank of the buildups.

Cores show that a thin laminated dolomite at the top of some mounds is commonly contorted, brecciated and fractured. This interval has been interpreted by Martindale and MacDonald as the result of hypersaline conditions or subareal exposure. Another interpretation is that the laminations are of stromatolitic origin and the strata in question have been subjected to vadose supratidal and peritidal conditions (Ehrets and Kissling, 1985). This facies, in conjunction with the overlying anhydrite, acts as a seal for the reservoir.

In their study, which included the majority of wells in the Tableland area, Martindale and MacDonald developed a diagenetic history which is recognizable in most cores examined in the study area.

Diagenesis in these dolomitized buildups started with the deposition of the grainstone shoals. Windward margins exhibit steeply-dipping foreslope beds which were stabilized by the precipitation of marine cements. Fracture systems infilled with cements and silts are also prevalent along the windward margins, and are probably syndepositional.

Fractures are also found near the tops of the buildups and these too are filled with marine sediment and cements. Martindale and MacDonald suggest that these are Neptunian fractures created by storm or tectonic activities and note that they are absent from the reef framework.

The development of the laminated dolostone cap and rare pendant cements are evidence of vadose diagenesis. Shallow and deep burial diagenetic processes produced dolomites, anhydrite and calcite cements and leached moldic and vuggy porosity. Physical compaction formed stylolites, and open fractures appear to post-date anhydritization but not oil migration, as they are typically oil stained.

3. Porosity Trends and Types

The porosity classification in this paper follows that of Choquette and Pray (1970). Most initial porosity was destroyed by early cementation, void sedimentation and late stage anhydritization. The dominant pore type is secondary intercrystalline which can vary from 0 to 15 percent, with typical values in the range of 4 - 8 percent. Secondary intercrystalline pore sizes are typically less than 62 microns in diameter.

Moldic, macrovug and mesovug porosity is primarily concentrated in the upper one third of the buildups. Moldic porosity is usually the result of the dissolution of brachiopods and ostracods. The larger vugs and some of the molds are generally lined with coarse (350-500 microns) euhedral dolomite and are partly occluded by bladed anhydrite cement. Vuggy porosity is also present in the remainder of the buildups but is usually only represented by microvugs and constitutes less than 10 percent of the total porosity.

Concentrations of chaetetids provide the majority of the intraskeletal porosity, which commonly ranges from less than 1 percent to 12 percent with pore sizes of 250-350 microns like that of the Chaetetid floatstone in 14-14-2-9W2M (Figure 3). Intraskeletal porosities provide roughly 5 percent of the total porosity.

Most of the primary shelter pores evident in the lower foreslopes have been filled with sediments and bladed anhydrite, and constitute less than 1 percent of the total porosity. Vertical and horizontal fractures occur sporadically throughout all cores examined. Analyses performed by Core Laboratories - Canada Ltd. indicate that permeability values are significantly greater where fractures are present. The fractures are generally oil stained, but account for less than 2 percent of the total porosity in the core.

4. Discussion

Reservoir quality is highly variable throughout the buildups. The lower foreslope facies tends to be generally

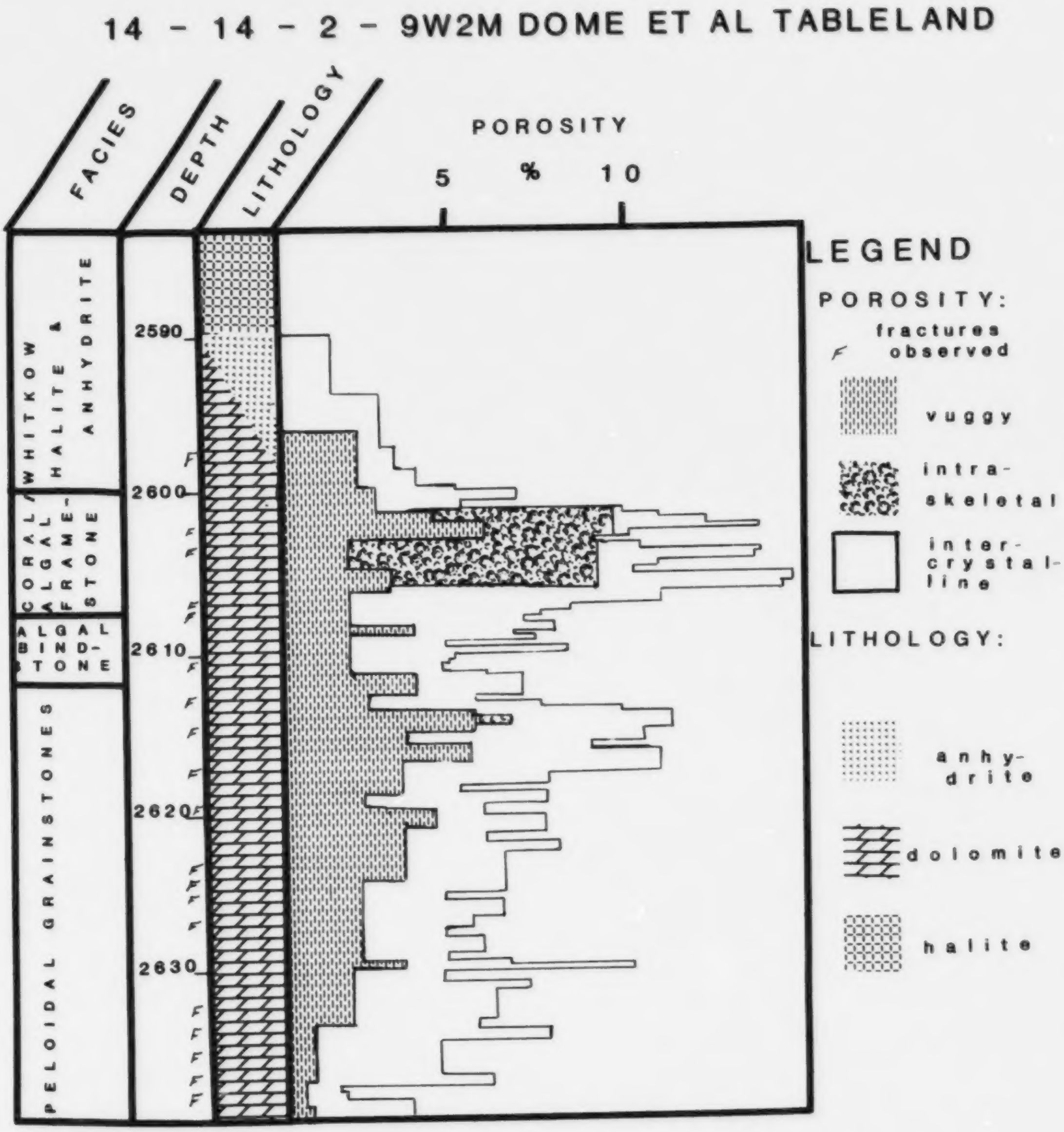


Figure 3 - Core graphic indicating major porosity trends.

poor because of the presence of the early marine cements. The reservoir quality of the other facies appears to be related to the degree of dolomitization which, if excessive, destroys the reservoir. Ehrets and Kissling (1985) suggest that this process may be related to Prairie salt solution and subsequent deep burial dolomitization.

As part of this study of reservoir porosities, mercury injection capillary pressure measurements will be analysed to try to determine the controls on porosity and permeability trends.

5. Acknowledgements

The author is currently doing research towards an M.Sc. degree under the supervision of Dr. D.M. Kent. Financial support for this research project is being provided by Saskatchewan Energy and Mines and is gratefully acknowledged.

6. References

Choquette, P.W. and Pray, L.C. (1970): Nomenclature and classification of porosity in sedimentary carbonates; Bull. Am. Assoc. Petrol. Geol., v54, p207-250.

Ehrets, J.R., and Kissling, D.L. (1985): Winnipegosis platform margin and pinnacle reef reservoirs, northwestern North Dakota; Soc. Econ. Paleontologists and Mineralogists, Core Workshop No. 7, p1-31.

Martindale, W. and MacDonald, R.W. (1989): Sedimentology and diagenesis of the Winnipegosis Formation, Tableland Area, southeast Saskatchewan; *in* Bloy, G., Hadley, M. and Curtis, B. (eds), The development of porosity in carbonate rocks, CSPG Continuing Education Short Course Notes.

Reinson, G.E. and Wardlaw, N.C. (1972): Nomenclature and stratigraphic relationships, Winnipegosis and Prairie Evaporite Formations, central Saskatchewan; Bull. Can. Petrol. Geol., v20, p301-320.

Sedimentology and Geochemistry of the Bakken Formation (Devonian-Mississippian) in Southern Saskatchewan

Ramez Karma[1] and G.R. Parslow[1]

Karma, R. and Parslow, G.R. (1989): Sedimentology and geochemistry of the Bakken Formation (Devonian-Mississippian) in southern Saskatchewan; *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

The Bakken Formation is well known as the premier marker in the Williston Basin because it comprises a gray sandstone bed sandwiched between two distinctively thin radioactive black shales, easily recognized in cores or on gamma-ray geophysical well logs. The Bakken is widely considered to be a source of hydrocarbons within the basin (Murray, 1968; Hayes, 1985). Fifty three drill cores that penetrated the Bakken in southern Saskatchewan (Figure 1) were examined and about 600 samples collected for geochemical analysis. Conodont samples were also collected and identified.

1. Bakken Formation

The Bakken Formation is one of the most distinctive stratigraphic sequences in the Williston Basin. This formation and its equivalents straddle the Devonian-Mississippian boundary throughout in the western interior region of the North American continent. In the Williston Basin this transition zone consists of three members: the Lower Bakken Shale, Middle Bakken Sandstone and Upper Bakken Shale.

a) Lower Bakken Shale

The Lower Bakken Shale unconformably overlies the Big Valley and Torquay Formations and the contact is marked in places by a lag-concentrate bed, a basal conglomerate, or an erosion surface. It is composed of homogeneous non-calcareous, carbonaceous to bituminous, fissile, massive, unconnected lenticular to thinly laminated, waxy, hard, pyritic, radioactive, dark gray to black shale. In some areas vertical fissures are filled by white calcite and disseminated pyrite. Christopher (1961) interpreted these fissures as compressed mud cracks. This member thins from 11 m in the west to zero in the east.

b) Middle Bakken Sandstone

A regional diastem separating the Middle Bakken Sandstone from the underlying member is shown by basal conglomerate, a weathering pavement, and truncation of the underlying Torquay Formation. Christopher (1961) divided this member into two lithological units, whereas Thrasher (1987), using macrofossils, proposed three subdivisions of the sandstone member. One of the authors (R.K.) found during core examination that both lithology and macrofossils should be used to distinguish the three units:

Unit I - The lowermost bed is 0 - 7 m thick, consists of a well-sorted, fine- to medium-grained, very calcareous, fossiliferous (brachiopods), unstratified (but in places shows traces of bedding), gray to dark brown, sandstone unit. Brachiopods are disarticulated, randomly oriented and indicate rapid sedimentation. This is supported by the lack of epifauna on the shells (Thrasher, 1987). The unit locally grades into an oolitic limestone or calcarenite bed (9-29-31-23W3, 8-20-31-23W3, 5-30-31-23W3). Pyrite nodules and disseminated pyrite grains are very common. In some areas this unit forms a good oil reservoir.

Unit II - The middle part of the sandstone member (1.5-7 m in thickness) comprises alternate dark gray to greenish gray shaley siltstone or sandstone beds that display numerous primary bedding features. Two interfingering sub-units can be recognized: 1) a pyritic, unfossiliferous, slightly calcareous, gray sandstone alternating laterally with thin, dark gray to black clay beds with predominant sedimentary features such as current bedding, ripple marks, cross bedding, channel fill and scour surfaces; and 2) a discontinuous bedding unit of silty sandstone to muddy siltstone, where the sandstone layers are spherically rolled into ellipsoids and broken into pebble size fragments along bedding surfaces.

Unit III - The topmost unit (0.6 to 2.5 m thick) consists of olive gray, non-calcareous, fossiliferous, bioturbated, pyritic, massive, argillaceous to silty shale.

c) Upper Bakken Shale

The upper Bakken shale conformably overlies the middle sandstone member and underlies the Lodgepole Formation. The member appears to have been formed during a repetition of the Lower Bakken shale depositional conditions as it has the same lithology.

2. Conodont Identification

Thirteen conodont samples were collected from 11 wells representing both the Upper and Lower Shale. No conodonts from the Middle Sandstone Member have been

---

(1) Geology Department, University of Regina, Regina, Saskatchewan.

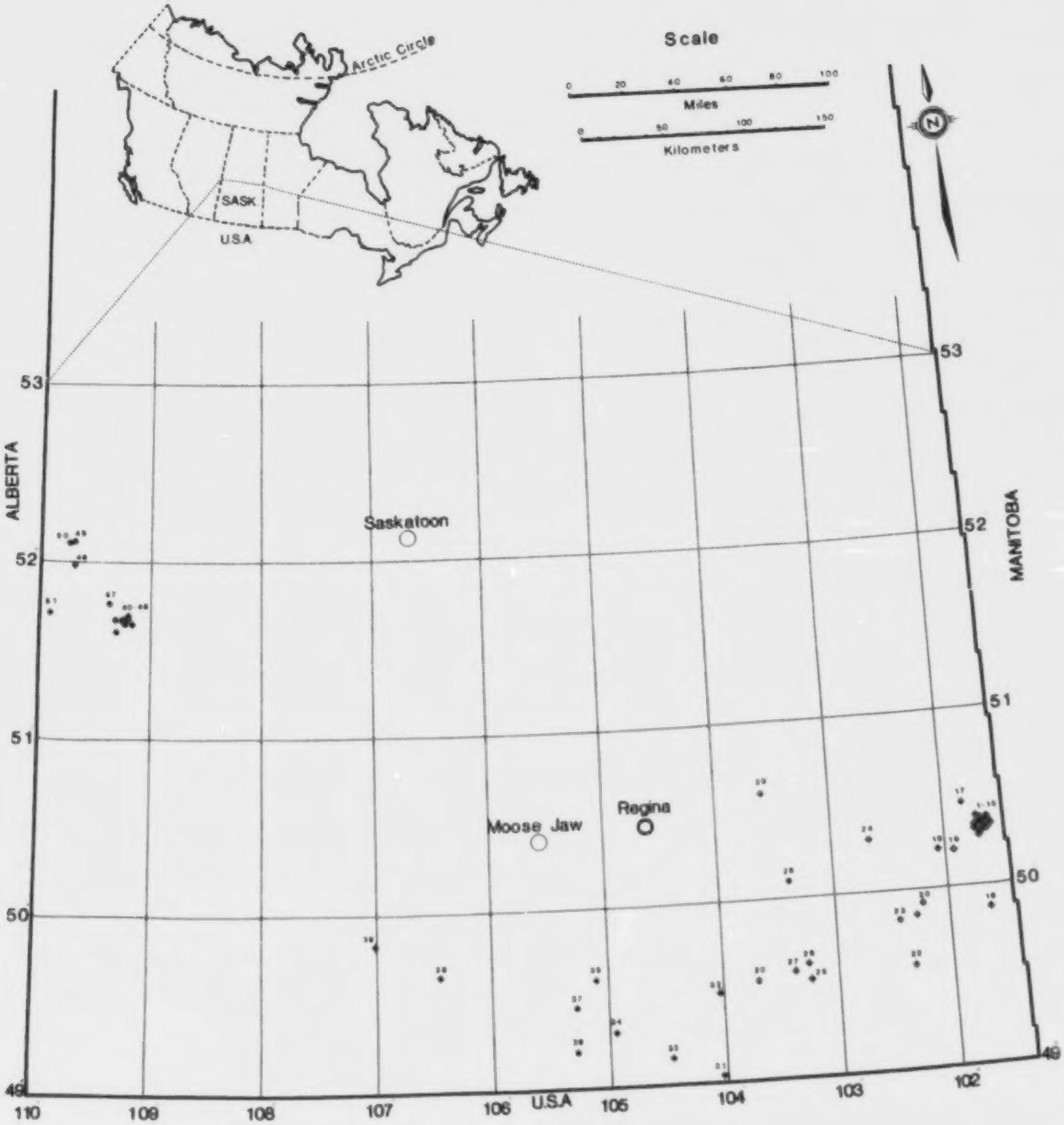

Arctic Circle
SASK
U.S.A
Scale
0
20
40
60
80
100
Miles
0
50
100
150
Kilometers
N
ALBERTA
MANITOBA
Saskatoon
Regina
Moose Jaw
53
52
51
50
49
110
109
108
107
106
U.S.A
105
104
103
102

Figure 1 - Borehole and sample location map (Saskatchewan).

observed. Initial examination was done with the aid of a hand lens (10X) or binocular microscope and then a more detailed study was carried out by Dr. Tom Uyeno of the Geological Survey of Canada, Calgary (samples are now stored at ISPG in Calgary).

a) Conodont Biozonation

In Upper Devonian-Lower Mississippian time, rapidly evolving platform elements provide the basis for conodont zonation. The base of each zone is usually defined by the stratigraphic first occurrence of a particular taxon. Sandberg (1979) reviewed the conodont zonation in this part of the Paleozoic (Figure 2) and concluded that the first occurrence of *Siphonodella sulcata* can be used to mark the Devonian-Mississippian boundary.

b) Composition and Distribution

Bakken conodonts are placed in 21 taxa (Figure 3). The collection is composed mostly of platform elements and rare ramiform elements. Platform genera include (in decreasing order of abundance) *Siphonodella*, *Polyg-*

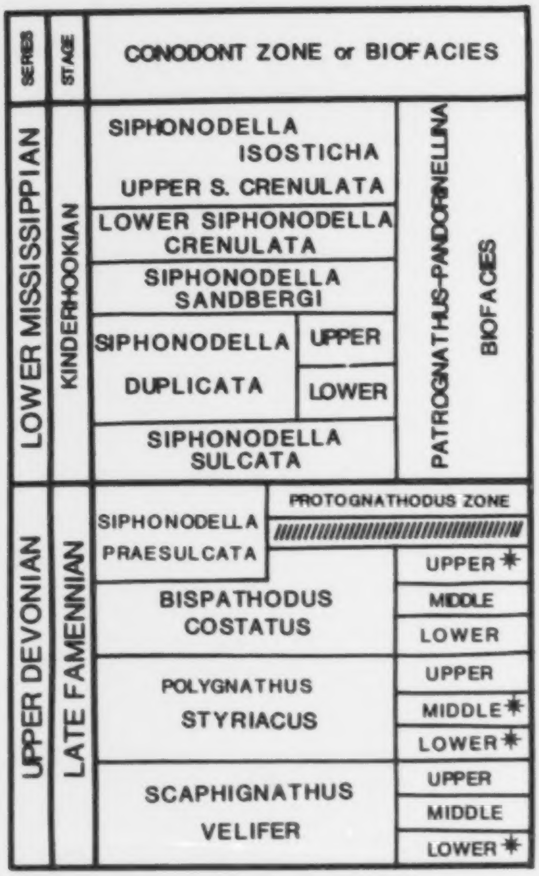

SERIES
STAGE
CONODONT ZONE or BIOFACIES
LOWER MISSISSIPPIAN
KINDERHOOKIAN
SIPHONODELLA ISOSTICHA
UPPER S. CRENULATA
LOWER SIPHONODELLA CRENULATA
SIPHONODELLA SANDBERGI
SIPHONODELLA DUPLICATA
UPPER
LOWER
SIPHONODELLA SULCATA
PATROGNATHUS-PANDORINELLINA BIOFACIES
UPPER DEVONIAN
LATE FAMENNIAN
SIPHONODELLA PRAESULCATA
PROTOGNATHODUS ZONE
BISPATHODUS COSTATUS
UPPER *
MIDDLE
LOWER
POLYGNATHUS STYRIACUS
UPPER
MIDDLE *
LOWER *
SCAPHIGNATHUS VELIFER
UPPER
MIDDLE
LOWER *

Figure 2 – Conodont biozonation after Saudbert (1979, Figures 2 and 3). Starred zones are those not recognized in the United States.

nathus, *Branmehla*, *Bispathodus*, *Pseudopolygnathus*, *Palmatolepis*, and "*Spathognathodus*". Distribution of the conodonts is mainly in the Upper and Lower Shales, being found mainly on shale bedding surfaces. Sixty-three per cent of the collection was obtained from the Upper Shale, the remainder from the Lower Shale.

c) Lower Shale

Based principally on the ranges established elsewhere (Sandberg, 1979; Holland *et al.*, 1987) the more diagnostic taxa in the Lower Shale include *Palmatolepis gracilis sigmoidalis*, *Palmatolepis rugosa rugosa* and *Bispathodus jugosus* (Uyeno, this study), and the absence of *Bispathodus aculeatus*, suggests that the Lower Bakken Shale can be assigned to the Upper *Polygnathus styriacus* zone (Lower-Middle *expansa* zone, Late Famennian).

d) Upper Shale

Since species identification requires three dimensional observation, the conodont evidence from this member is not precise because the fractured specimens of *Siphonodella* could not be extracted intact. However the presence of *Bispathodus aculeatus* suggests that the Upper Shale is no younger than the Lower *crenulata* Zone (Middle Kinderhookian). This is also confirmed by the presence of "*Spathognathodus*" *macer*. Hayes (1985) and Holland *et al.* (1987) also suggested a Lower *crenulata* age for this member in North Dakota.

e) Conodont Color Alteration Index (CAI)

Harris (1981) reported that "color alteration begins beyond the threshold of hydrocarbon generation and a CAI of 1.5 to 2 is at the deadline for oil and condensate production". Conodonts from both Upper and Lower Bakken Shale have CAI values (Epstein *et al.*, 1977) of 1 (pale yellow) to 1.5 (pale brown). Since the conodont samples were collected from depths ranging between 800 and 2350 m, this suggests that the enclosing rocks are thermally immature between these depths and therefore not sufficiently heated for hydrocarbon generation.

3. Geochemistry of the Bakken Formation

Some 569 samples were collected from the 53 subsurface cores shown in Figure 1 in an attempt to 1) establish the nature of the Bakken Formation gamma-ray response, 2) identify any regional trends in the "radioactivity", 3) determine general major and trace element concentrations, and 4) identify possible factors controlling elemental concentrations.

a) Analytical Methods

All samples were analyzed for SiO_2, TiO_2, Al_2O_3, total Fe_2O_3, MnO, MgO, CaO, P_2O_5 by ICP; Na_2O and K_2O by AAS; H_2O and LOI by gravimetry; Ba, Cr, Cu, Nb, Ni, Pb, Rb, Sr, Th, U, V, Y, Zn, Zr by XRF. FeO(c) was calculated as representing 90% of total Fe_2O_3 and it should be noted that LOI represents an approximation of combined, inorganic and organic carbon plus organic sulphur. In addition, all samples were analyzed for U and Th by NAA; the activation analyses are presented in the following tables as they are more precise than those obtained by XRF.

Since some samples contained significant pyrite, which is not readily accounted for by an LOI procedure, 23 samples of the Lower Shale, 30 samples of Middle Sandstone, and 28 samples of Upper Shale were analyzed for S by XRF. A limited number of samples (44 Lower Shale, 36 Middle Sandstone, 39 Upper Shale) were analyzed by NAA for 34 elements, namely: Au, Ag, As, Ba, Br, Ca, Co, Cr, Cs, Fe, Hf, Hg, Ir, Mo, Na, Ni, Rb, Sb, Sc, Se, Sr, Ta, Th, U, W, Zn, and the REE-La, Ce, Nd, Sm, Eu, Tb, Yb, Lu. Finally, seven samples of shale were subjected to solvent extraction and the rock residues and oil extracts were analyzed for 34 elements by NAA.

CONODONT TAXA	LOWER SHALE	UPPER SHALE	DEPTH (M)	SAMPLE &WELL LOCATION
Bispathodus aculeatus aculeatus		*	1675.8	6-9-7-13 W2
		*	2324.7	2-14-1-16 W2
		*	792.75	9-29-31-23W3
		*	844-845	10-33-30-24W3
Bispathodus jugosus	*		1819.9	1-2-6-25W2
	*		849.7-851	10-33-30-24W3
Bispathodus stabilis		*	792.75	9-29-31-23W3
		*	844-845	10-33-30-24W3
Branmehla inornata	*		1689.4	15-7-7-10W2
	*		1819.9	1-2-6-25W2
	*		835.9	5-30-31-23W3
	*		849.7-851	10-33-30-24W3
Palmatolepis gracilis sigmoidalis	*		1819.9	1-2-6-25W2
	*		849.7-851	10-33-30-24W3
Palmatolepis perlobata postera	*		849.7-851	10-33-30-24W3
Palmatolepis rugosa rugosa	*		849.7-851	10-33-30-24W3
Polygnathus communis communis		*	686.8	16-5-16-31W1
		*	1675.8	6-9-7-13W2
		*	2324.7	2-14-1-16W2
		*	792.75	9-29-31-23W3
		*	844-845	10-33-30-24W3
Polygnathus inornatus		*	1675.8	6-9-7-13W2
Polygnathus ?sp.		*	811.4	8-26-31-24W3
Pseudopolygnathus marginatus		*	654.1	16-11-16-31W1
		*	1675.8	6-9-7-13W2
		*	2324.7	2-14-1-16W2
		*	792.75	9-29-31-23W3
		*	844-845	10-33-30-24W3
Pseudopolygnathus primus		*	1675.8	6-9-7-13W2
Pseudopolygnathus ch.p. brevipennatus	*		849.7-851	10-33-30-24W3
Pseudopolygnathus sp.		*	792.75	9-29-31-23W3
Siphonodella sp.		*	792.75	9-29-31-23W3
"Spathognathodus" crassidentatus		*	792.75	9-29-31-23W3
Spathognathodus strigosus	*		1819.9	1-2-6-25W2
	*		849.7-851	10-33-30-24W3
"Spathognathodus" sp.	*		1689.4	15-7-7-10W2
	*		2324.5	2-14-1-16W2
	*		849.7-851	10-33-30-24W3
"Spathognathodus" elongatus		*	811.4	8-26-31-24W3
"Spathognathodus" macer		*	1675.8	6-9-7-13W2
		*	2324.7	2-14-1-16W2
		*	792.75	9-29-31-23W3
		*	844-845	10-33-30-24W3
Ramiforms		*	1784.95	3-26-6-16W2
		*	811.4	8-26-31-24W3
	*		2324.5	2-14-1-16W2

Figure 3 – Distribution of conodonts obtained froom the Lower and Upper Bakken Shales. Depths are from the core boxes.

The analytical work has just been completed and interpretation of the data about to commence. However, a few observations of a preliminary nature are noted in this report, based mainly on the analyses noted in the first paragraph of the above section on analytical methods.

b) Bakken Shale vs Other Shales and Black Shales

Table 1 shows the published values of shales and black shales with the average Bakken shale (379 samples) for some of the elements analyzed in this study. As expected the major elements are generally conformable, except that perhaps the Bakken is depleted slightly in FeO and enriched slightly in K_2O (a natural radioelement). Most of the trace elements are generally conformable, except that Cr, Ni, U, and especially V and Zn, are enriched. With Th values a little below average, it is clear that the gamma-ray response of the Bakken Formation on well logs is predominantly U generated.

c) Lower Shale Member

The 192 samples of Lower Shale (some selected analyses are shown in Table 2) have been subdivided into groups based on LOI and tables of basic statistics for these subgroups are available from the authors. The LOI boundaries used are 0-10%, 10-20%, 20-30%, 30-40% and >40%. The majority of samples fall in the 0-30% range. The 2 samples >40% have high CaO values because they are calcareous units.

The general observation is that U, V, Pb, Cr, Ni and Zn exhibit a clear positive correlation with LOI, while Th tends to have a negative correlation. A tentative conclusion is that these elements other than Th must have had their precipitation controlled by organic matter.

Adams and Weaver (1958), based on the Th/U ratio, reported three geochemical facies in sedimentary rocks and concluded (page 419) that the low Th/U ratio of

Table 1 – Comparison of Bakken Shale Average with Other Published Data.

Element	Average(1) Exshaw shale	Black(2) Shale	Average(3) Shale	Average(4) Black Shale	Average Bakken Black Shales
SiO_2	48.5	58.6	58.1	-	50.15
TiO_2	0.30	0.42	0.77	0.33	0.55
Al_2O_3	7.20	9.65	15.1	13.2	11.96
FeO	3.88	4.46	6.75	2.86	2.79
MnO	-	-	-	-	0.035
MgO	1.21	0.84	2.49	1.16	2.39
CaO	4.92	1.69	3.09	2.10	4.3
Na_2O	0.30	0.34	1.29	0.94	0.54
K_2O	2.67	3.32	3.20	2.41	4.89
P_2O_5	-	-	-	-	0.31
H_2O	-	-	-	-	0.84
LOI	-	-	-	-	20.69
Ba	325	355	580	300	402.01
Cr	55.3	66	90	100	407.66
Cu	72	82	45	70	85.2
Nb	-	-	-	-	10.35
Ni	107	123	68	50	315.05
Pb	26	30	20	20	35.84
Rb	78	101	140	-	134.48
Sr	222	157	300	200	163.40
Th	9.2	10.7	12	-	8.34
U	15.6	15.9	3.7	-	52.81
V	227	267	130	150	4851.16
Y	-	-	26	30	35.76
Zn	102	108	95	300	1041.42
Zr	-	-	160	70	139.89

(1) Average Exshaw shale values from Duke (1983)
(2) Black shale values from Duke (1983)
(3) Average shale values from Cambel et al. (1983) after Turekian and Wedepohl (1961)
(4) Average black shale values from Vine and Tourtelot (1970).

Major elements in weight percent, trace element in ppm

0.31 in the Heebner black shale indicated reducing conditions, favourable for carbonaceous material accumulation, as well as for extraction of the uranyl ion from the seawater during very slow rates of sedimentation. The Bakken Th/U ratio of 0.18 suggests even more extreme depositional conditions (of reduction) than were present for the Heebner shale.

d) Middle Sandstone Member

Table 3 shows a selection of sandstone analyses from the 196 samples analyzed. General statistics were calculated based on the same LOI subdivison was used for the Lower Shale data. Compared with the Lower Shale it is clear that the LOI in the Middle Sandstone is predominantly controlled by inorganic carbon because the CaO increases proportionally with the LOI. As a consequence the enhancements of U, V, Pb, Cr, Ni, Zn noted in the Lower Shale with increasing LOI are either weak (Pb, Ni, Zn) or actually reversed (i.e. depletions of U, V, Cr).

Generally, the trace element contents are low; particularly U. On the other hand, the Th/U ratio is high (1.18).

e) Upper Shale Member

Analyses of the 178 samples in this member exhibit very similar elemental values to the other members (Table 4 - selected analyses). The conditions of formation of this member must have been almost identical to those of the Lower Shale.

4. Nature of Elemental Bonding

It is perhaps premature, at this stage in the study, to present views on the bonding of the "anomalous" concentrations of trace elements; however, the results from the rock residues and extracted oils indicate that almost all the trace elements are, and remain in, the rock, not in the oil. Thus, although the organic material must have played an important part in the production of the right conditions for the precipitation of the trace elements, the actual precipitation and bonding was an inorganic process.

5. Acknowledgements

The authors express acknowledgement to Saskatchewan Energy and Mines and the University of Regina for their financial support to this project.

The first author (R.K.) wishes to acknowledge the fellowship granted by the International Atomic Energy Agency, which has allowed him to pursue this research as part of his M.Sc. program in the Geology Department at the University of Regina.

Sincere thanks to the subsurface laboratory staff for their cooperation during core examination, to

Table 2 – Selected Analysis from Lower Bakken Shale Mean and S.D. Values based on all 192 Lower Bakken Shale Samples.

Sample#	25	32	150	224	263	313	401	420	450	528	556	Mean	S.D.
SiO2	86.22	49.24	56.12	60.99	53.61	64.73	57.19	45.03	40.79	2.94	52.09	53.83	10.25
TiO2	0.63	0.60	0.40	0.78	1.20	0.80	0.68	0.57	0.52	0.03	0.60	0.59	0.17
Al2O3	7.22	14.41	8.67	18.57	12.39	16.62	15.74	11.87	11.63	0.56	16.90	12.98	3.71
Fe2O3	0.07	0.34	0.14	0.38	0.29	0.36	0.31	0.27	0.36	0.01	0.31	0.32	0.21
MnO	0.00	0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.04	0.35	0.02	0.04	0.11
FeO(c)	0.59	2.77	1.14	3.04	2.32	2.94	2.53	2.16	2.93	0.10	2.47	2.57	1.70
MgO	0.76	1.85	1.67	1.83	1.01	1.95	1.52	2.32	2.54	0.46	1.72	2.08	0.87
CaO	0.09	0.58	4.22	0.14	5.14	0.30	0.16	2.31	5.37	54.93	0.67	3.09	5.30
Na2O	0.17	0.53	0.53	0.53	0.53	0.59	1.88	0.52	0.41	0.05	0.59	0.59	0.29
K2O	1.55	4.01	3.74	6.62	4.38	6.42	6.40	4.77	6.60	0.13	4.03	5.03	1.44
P2O5	0.20	0.41	0.24	0.14	2.85	0.19	0.23	0.32	0.93	0.09	0.45	0.33	0.41
H2O-	0.19	1.95	0.45	0.00	0.00	0.00	0.93	0.45	1.37	0.09	0.12	0.71	0.60
LOI	2.31	23.22	22.42	6.92	16.29	6.15	12.42	29.09	26.54	40.79	20.02	17.32	9.33
TOTAL	100.00	99.92	99.76	99.95	100.02	101.07	100.00	99.70	100.03	100.53	99.99		
Ba	168	247	115	322	377	293	261	164	206	1	319	308.37	529.77
Cr	97	151	91	124	160	132	1413	1151	714	1279	1077	460.02	477.94
Cu	7	83	39	198	312	40	110	67	92	8	63	71.71	93.00
Nb	12.0	12.0	8.0	14.0	23.0	14.0	15.0	11.0	15.0	1.0	14.0	11.15	3.26
Ni	8	36	345	130	205	310	957	533	601	12	497	286.57	216.50
Pb	7	30	9	106	84	61	27	26	193	5	32	29.15	25.25
Rb	61	176	107	235	176	202	176	128	111	22	135	150.59	47.24
Sr	44	99	46	206	204	59	66	50	117	220	356	207.24	1016.17
Th	0	1	4	13	13	9	16	8	8	1	17	8.58	3.31
U	5	52	126	460	240	86	110	180	1500	4	54	62.91	117.69
V	69	3182	1219	791	361	897	15407	12958	2266	29111	18609	5299.91	7619.12
Y	34	71	43	23	145	21	59	66	73	7	43	35.44	28.31
Zn	28	1292	1677	232	134	191	178	2189	3523	26	2986	859.54	3735.05
Zr	498	148	97	183	244	187	149	117	137	32	170	142.91	51.35

Table 3 – Selected Analyses from Middle Bakken Sandstone member. Mean and S.D. Values based on all 196 Middle Bakken Sandstone Samples.

Sample#	10	16	43	53	79	182	220	376	517	567	Mean	S.D.
SiO_2	85.73	67.27	43.38	54.66	49.37	44.84	55.06	77.76	63.57	43.38	56.22	13.45
TiO_2	0.40	0.79	0.45	0.25	0.49	0.22	0.34	0.32	0.59	0.41	0.38	0.14
Al_2O_3	5.36	14.83	7.95	4.41	9.43	3.07	5.80	5.49	7.38	6.50	6.31	2.70
Fe_2O_3	0.23	0.39	0.21	0.12	0.21	0.07	0.15	0.09	0.18	0.16	0.17	0.10
MnO	0.01	0.02	0.08	0.05	0.05	0.07	0.06	0.02	0.04	0.12	0.06	0.03
$FeO(c)$	1.84	3.19	1.73	0.95	1.68	0.54	1.20	0.72	1.49	1.31	1.38	0.83
MgO	0.78	1.26	5.94	4.63	5.47	6.96	6.76	2.10	3.82	3.41	4.87	2.43
CaO	0.23	0.34	13.78	16.21	11.09	19.26	11.68	4.38	6.56	20.30	11.74	6.23
Na_2O	0.18	0.32	0.45	0.35	0.65	0.37	0.55	0.96	0.22	0.20	0.53	0.35
K_2O	1.00	2.40	3.67	2.33	5.60	1.88	3.19	2.52	3.05	2.58	2.86	1.21
P_2O_5	0.23	0.85	0.25	0.41	0.27	0.21	0.11	0.30	0.23	0.21	0.21	0.08
H_2O^-	0.29	1.92	0.63	0.20	0.13	0.05	0.00	0.14	0.42	0.39	0.34	0.42
LOI	3.73	6.41	20.72	15.38	15.10	22.45	13.74	5.22	12.49	20.68	14.79	5.78
TOTAL	100.01	99.99	100.24	99.95	99.54	99.99	98.64	100.02	100.04	99.65		
Ba	116	1246	159	204	179	102	254	149	185	134	252.72	519.39
Cr	194	237	76	54	79	41	65	70	684	0	206.10	277.02
Cu	39	86	12	24	11	35	13	16	15	12	11.39	8.49
Nb	6.0	18.0	9.0	5.0	10.0	5.0	6.0	6.0	9.0	7.0	6.80	2.75
Ni	12	28	35	32	38	46	37	22	25	18	33.04	28.23
Pb	39	133	22	5	9	8	15	7	11	10	14.29	17.17
Rb	53	123	98	57	103	36	71	60	83	73	70.64	27.25
Sr	33	1461	71	124	174	138	76	143	65	98	123.52	236.91
Th	6	10	6	5	7	5	5	7	10	6	6.15	2.14
U	9	49	14	3	1	5	15	23	7	3	5.20	5.28
V	285	1906	88	54	108	79	61	112	691	0	433.47	1629.01
Y	51	99	32	26	24	22	19	26	25	28	23.16	7.83
Zn	64	102	153	10	41	43	169	7	21	19	59.04	154.58
Zr	394	417	188	302	181	329	227	254	307	184	248.20	89.50

Holly Paluck for her assistance in sample preparation, and finally to Wendy Petrisor for typing this paper.

6. References

Adams, J.A.S. and C.E. Weaver (1958): Thorium-uranium ratios as indicators of sedimentary processes: example of concept of geochemical facies; Bull. AAPG, v42(2).

Cambel, B. and M. Khum (1983): Geochemical characteristics of black shales from the ore-bearing complex of strata of the Male Karpaty Mts.; Geologicky Zbornik, v34(3), p259-382.

Christopher, J.E. (1961): Transitional Devonian-Mississippian formations of southern Saskatchewan; Sask. Dept. of Miner. Resour., Rep. 66.

Duke, M.J.M. (1983): Geochemistry of the Exshaw shale of Alberta - an application of Neutron Activation Analysis and related techniques; unpubl. Msc. thesis.

Epstein, A.G., J.B. Epstein and L.D. Harris (1977): Conodont color alteration - an index to organic metamorphism; U.S. Geol. Surv., Prof. Pap. 995, 27p.

Harris, A.G. (1981): Color alteration - an index to organic metamorphism in conodont elements; *in* Robinson, R.A. (ed.), Treatise on Invertebrate Paleontology, part W, Miscellanea supplement 2; Boulder, Colorado and Lawrence, Kansas, Geol. Soc. Am. and Univ. Kansas, pW56-W60.

Hayes, M.D. (1985): Conodonts of the Bakken formation (Devonian-Mississippian) Williston Basin, North Dakota; The Mountain Geologist, v22(2), p64-77.

Holland, F.D., Hayes, M.D., Thrasher L.C. and Huber T.P (1987): Summary of the biostratigraphy of the Bakken Formation (Devonian-Mississippian) in the Williston Basin, North Dakota; 5th International Williston Basin Symposium, p68-76.

Murray, G.H., Jr. (1968): Quantitative fracture study - Sanish pool, McKenzie County, North Dakota; A.A.P.G. Bull., v52(1), p57-65.

Sandberg, C.A. (1979): Devonian and Lower Mississippian Conodont Zonation of the Great Basin and Rocky Mountains; *in* Sandberg, C.A. and Clark, D.L. (eds.), Conodont Biostratigraphy of the Great Basin and Rocky Mountains, Brigham Young University Geology Studies, v26(3), p87-105.

Thrasher, L.C. (1987): Macrofossils and stratigraphic subdivisions of the Bakken Formation (Devonian-Mississippian) Williston Basin, North Dakota; 5th International Williston Basin Symposium, p53-67.

Table 4 – Selected Analyses from Upper Bakken Shale Member. Mean and S.D. Values based on all 178 Upper Bakken Shale Samples.

Sample#	**2**	**5**	**8**	**9**	**56**	**227**	**316**	**372**	**380**	**413**	**538**	**Mean**	**S.D.**
SiO_2	62.93	66.67	60.74	51.12	42.68	34.43	55.22	37.21	36.79	39.50	34.76	46.46	10.57
TiO_2	0.44	0.57	0.77	0.64	0.50	0.39	0.66	0.40	0.43	0.45	0.44	0.50	0.12
Al_2O_3	9.94	11.82	16.49	12.33	9.78	8.96	14.40	9.41	10.25	9.06	8.79	10.94	3.17
Fe_2O_3	0.15	0.27	0.38	0.29	0.18	0.37	0.41	0.37	0.49	0.19	0.29	0.30	0.13
MnO	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.02
FeO(c)	1.22	2.18	3.11	2.31	1.45	2.99	3.32	2.98	3.94	1.54	2.31	2.40	1.03
MgO	1.14	1.38	1.65	1.33	2.43	1.69	2.44	1.81	1.40	1.83	1.30	2.70	1.72
CaO	9.91	0.09	0.10	0.08	2.93	2.16	4.09	2.30	1.13	1.75	3.56	5.52	6.28
Na_2O	0.34	0.34	0.43	0.34	0.64	1.19	0.55	0.88	0.80	0.35	0.31	0.49	0.22
K_2O	2.35	3.26	3.75	2.80	4.28	4.28	6.57	4.53	4.49	4.23	3.21	4.75	1.34
P_2O_5	0.40	0.20	0.25	0.22	0.31	0.42	0.38	0.27	0.29	0.31	0.22	0.29	0.15
H_2O-	0.58	1.07	1.30	1.10	0.79	0.00	1.29	1.73	1.66	0.29	1.64	0.97	0.69
LOI	10.63	11.45	10.93	27.46	33.25	43.12	10.64	38.12	38.29	39.48	34.58	24.07	11.22
TOTAL	100.05	99.31	99.91	100.03	99.24	100.02	99.99	100.03	99.99	99.00	91.43		
Ba	133	237	308	182	127	170	229	96	131	105	140	495.65	1431.62
Cr	101	119	137	217	124	113	153	0	109	1256	500	355.31	448.77
Cu	29	38	37	127	97	102	72	119	238	126	113	98.69	125.74
Nb	8.0	9.0	15.0	12.0	9.0	6.0	12.0	10.0	10.0	10.0	10.0	9.55	2.62
Ni	19	124	100	397	443	586	220	512	1048	597	784	343.53	209.56
Pb	19	28	41	54	24	81	8	158	91	41	36	42.53	46.41
Rb	88	131	175	122	109	94	174	92	107	97	95	118.37	36.78
Sr	114	50	107	100	56	49	108	60	39	43	119	119.56	265.71
Th	8	7	10	8	6	7	7	7	8	8	11	7.89	2.28
U	3	22	116	262	54	75	14	260	190	91	37	42.71	41.19
V	220	369	456	3033	2071	1432	1217	0	1358	19044	3438	4402.41	7286.56
Y	40	21	39	69	44	45	51	40	85	34	20	36.08	15.53
Zn	84	162	81	3487	404	3151	57	9707	6271	410	24342	1223.29	3143.97
Zr	117	210	202	290	137	89	133	88	89	115	164	136.88	45.62

Turekian, K.K. and K.H. Wedepohl (1961): Distribution of the elements in some major units of the earths crust; Geol. Soc. Amer. Bull., v72(2), p175-191.

Uyeno, T.T. (1989): Report on 13 conodont samples from the lower and upper shale members of the Bakken Formation from 11 wells in southern Saskatchewan; Geol. Surv. Can., Rep. 08-TTU-89.

Vine, J.D. and Tourtelot, E.B. (1970): Geochemistry of black shale deposits - A summary report; Econ. Geol., v65, p253-272.

Industrial Minerals Program

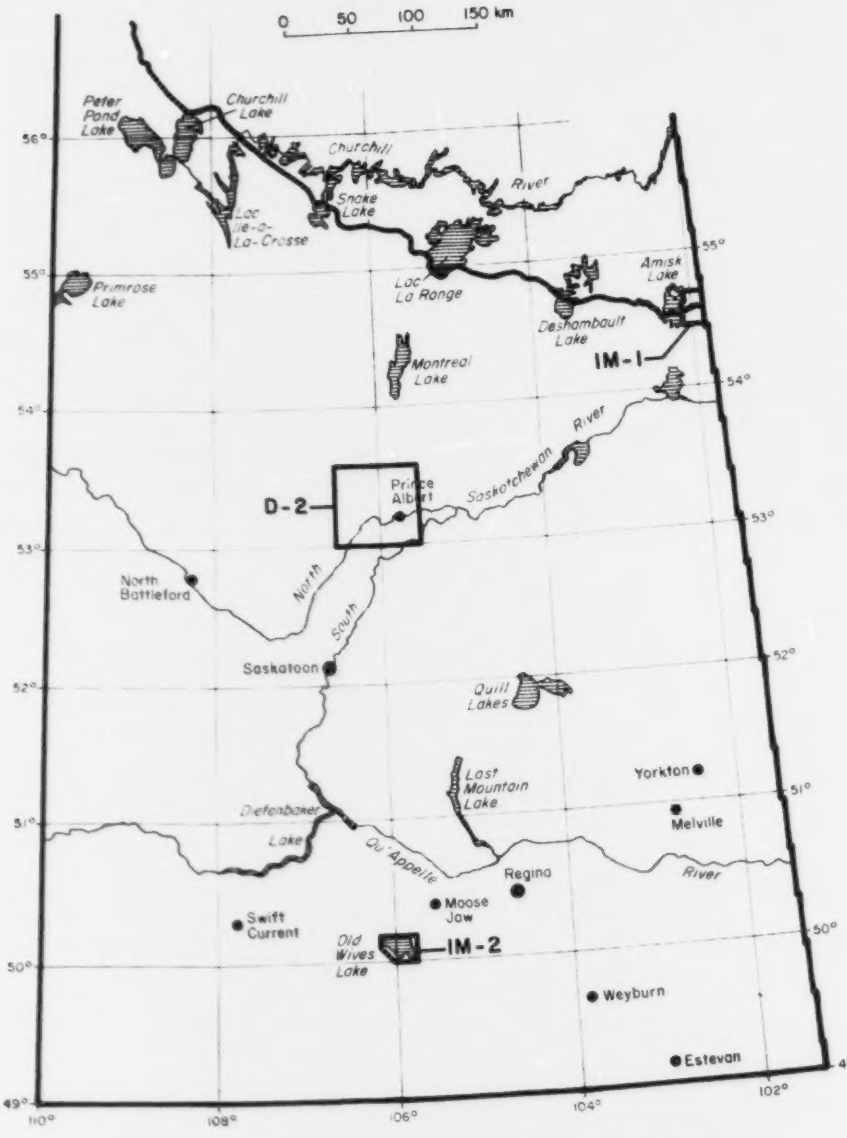

0
50
100
150 km
Peter Pond Lake
Churchill Lake
Churchill
River
Snake Lake
Lac Île-à-La-Crosse
Primrose Lake
Lac La Ronge
Deschambault Lake
Amisk Lake
IM-1
Montreal Lake
Saskatchewan
River
D-2
Prince Albert
North Battleford
North
South
Saskatoon
Quill Lakes
Last Mountain Lake
Yorkton
Melville
Diefenbaker Lake
Qu'Appelle
River
Regina
Moose Jaw
Swift Current
Old Wives Lake
IM-2
Weyburn
Estevan
56°
55°
54°
53°
52°
51°
50°
49°
110°
108°
106°
104°
102°

Figure 1 – Location of Industrial Minerals and Kimberlite projects

Industrial Minerals Projects

IM-1: Building Stone Evaluation in the Creighton - Denare Beach area: (Contract project reported by P. Guliov)

IM-2: Old Wives Lake Investigation

IM-3: Availability and Markets of Structural Industrial Minerals in Saskatchewan: Contracted to Saskatchewan Research Council (Includes a broad range of minerals from various areas)

IM-4: Three Major Processes Leading to the Deposition and Preservation of Potash Salts of the Prairie Evaporite in Saskatchewan: D. Lane (Includes the potash region of southern Saskatchewan)

Kimberlite (Diamond) Studies

D-1: Regional Phanerozoic Anomalies: M. Gent (Includes the entire Phanerozoic Basin)

D-2: Air Photo-Remote Sensing in the Prince Albert area: (Contract project in planning stage)

Review of Industrial Minerals Investigations 1989-90

P. Guliov

Guliov, P. (1989): Review of Industrial Minerals investigations 1989-90; *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

The Sedimentary Geodata Branch undertook or contracted projects (Figure 1) to study:

1) a variety of industrial commodities (building stone, sodium sulphate, subsurface brines and potash);
2) the availability of and markets for structural materials (clay, aggregates, lime and gypsum) and
3) the origin of amomalous conditions in Phanerozoic rocks and the potential application of Remote Sensing to the search for kimberlitic rocks and possibly diamonds.

1. Building Stone Project: No. A5.01, P. Guliov

The Project is a preliminary examination of Precambrian and Ordovician rocks in the Creighton-Denare Beach area from the dimension stone resource perspective. Four Precambrian rock units and Ordovician dolomites were investigated and five bulk samples taken. The area has good potential for yielding attractive stone of block sizes suitable for processing into a variety of building products. Preliminary results (Guliov, this volume), indicate suitable resource potential for quarrying and a need for detailed site-specific investigations on at least four of the lithotypes. The final report is expected to be released in December, 1989.

2. Old Wives Lake Project: No. 5.03, D.M. Lane

Project OWL attempts to increase the knowledge of the stratigraphy and mineral potential of the Old Wives Lake basin. The basin is a catchment covering about 37,000 ha and drawing on an area of about 1.2 million ha. Inflow comprises direct precipitation, surface runoff, small streams, the Wood River and groundwater discharge. The geology of the drainage basin includes clastic rocks and sediments of late Cretaceous, Tertiary (including lignites), Pleistocene and Recent age. The diverse lithology of the drainage basin and the potential for concentrations of various major and trace elements in the stagnant water of Old Wives Lake offer an interesting prospect for economically-oriented investigation.

Background work on the project is in progress; however, access to the lake bed by coring equipment is dependent either on continued dry conditions or on a hard freeze during the winter. The lake bed was not accessible during the summer of 1989 due to relatively high precipitation and runoff.

3. Availability and Markets of Structural Industrial Minerals in Saskatchewan. No. A5.02, Saskatchewan Research Council

This project, scheduled for completion by March 1990, examines structural industrial minerals in terms of provincial requirements, nature of utilization, specifications, production, sources of supply, resources, exports, imports and prices. Included in this group of minerals are:

(a) clays – stoneware, ball brick, kaolin, bloating and bentonites,
(b) clay products – structural and face brick, refractories, lightweight aggregate, sewer pipe, vitrified flue lining, floor and wall title,
(c) silica sand,
(d) lime, limestone and dolomite (including cement rock), crushed stone and building stone in general,
(e) sand and gravel and
(f) gypsum

the principal objectives of the project are:

(a) to outline the provincial supply and demand for these minerals and the nature of their application in industry,
(b) to present a general overview of resource distribution and quality and
(c) to assess the market outlook and opportunities for development.

4. Saskatchewan Subsurface Brines in the Souris River, Dawson Bay and Winnipegosis Formations: D.M. Lane

Several brine occurrences in Devonian formations are rich in calcium and magnesium chloride. Significant concentrations of bromine, iodine and boron are associated with such brines locally. Preliminary investigations to determine the economic potential of the brine resources include:

(a) stratigraphic and areal distribution of brines and their concentration,
(b) brine composition and variation,
(c) mechanism of entrapment and
(d) resource potential

5. Deposition and preservation of Potash Salts of the Prairie Evaporite in Saskatchewan: D.M. Lane

This project examines the complex interrelationship of gypsum, anhydrite, carnallite, potash and limestone in the potash-bearing region of Saskatchewan. It traces the chemical and physical evolution of these lithologic units and proposes a general model for the genesis and preservation of potash salts. The processes at work in the diagenetic history of the lithotypes are also discussed in the context of their implications in the accumulation of potentially economic resources of brine, petroleum and gas. The project is summarized by Lane (this volume).

6. Regional Phanerozoic Anomalies: No. A4.01, M.R. Gent

This project entails compilation and interpretation of available data and gathering of new data which may relate to the occurrence and distribution of kimberlites and other intrusive rocks in the Phanerozoic region of the province. Generally the scope of the investigation encompasses a wide variety of data including geophysics, structure, geochemistry, mineralogy and remote sensing. The principal objective is, at best, to develop a preliminary model or at least, a general framework for diamond and other precious gem prospecting in the sedimentary basin of the province. Work is well underway and reported upon by Gent (this volume).

7. Air Photo Remote Sensing Project: No. A4.03 (to be initiated}

This project will attempt to identify, interpret and classify linear and non-linear features in the Prince Albert – Shellbrook area which may correlate with basement structure and the occurrence of diatremes and related intrusions. The area is chosen for its known kimberlite occurrences. Imagery to be used includes air photos at several levels of detail, Landsat imagery and airborne radar imagery of low resolution if it becomes available for the area during the project. Wherever possible seismic and aeromagnetic survey data will be used in conjunction with the above.

Building Stone Investigations in the Creighton - Denare Beach Area

Paul Guliov

Guliov, P. (1989): Building stone investigations in the Creighton - Denare Beach area; *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

The following account is based largely on work contracted to Mr. G. Pearse of Agricola Mineralia, Navan, Ontario. Field investigations of building stone resources were conducted in the Creighton - Denare Beach area (Figure 1) during the month of August. Examination of about 180 outcrops within about 1 to 2 km of roads concentrated on:

(a) the Phantom Lake porphyritic granite,
(b) the metagabbros in the Wekach and Mystic Lakes areas,
(c) the quartz-eye diorite on the east shore of Amisk Lake,
(d) granodiorite and
(e) Ordovician dolomites.

Detailed fracture pattern measurements were made on the Phantom Lake granite, Mystic Lake metagabbro and Ordovician dolomite over areas ranging from about 1000 to 2000 m^2 (Figure 2). Five bulk samples of about 500 kg each were taken for compressive strength tests, polishing tests and other technical and aesthetic evaluation. Preliminary observations (including fracture pattern measurements) suggest a reasonably good potential for attractive granitic and dolomitic dimension stone in block sizes suitable for large-scale processing. As sample preparation and testing are under way at the time of writing, it is premature to draw any hard conclusions as to the technical merits of the various rocks as building stones.

1. Mystic Lake Metagabbro

The Mystic Lake metagabbro, a fine-grained black to green rock, is of greatest interest from the market demand aspect. Varieties include: massive black metagabbro, black with pink phenocrysts and (in areas adjoining granodiorite) dark green, veined with felsic material derived from the granodiorite. The latter variety is reminiscent of a commercial stone from Vermont known as "verde antique" and could be classified as a "marble" in the dimension stone industry. Exposures extending from Wekach Lake southward and in the area immediately west of Mystic Lake are promising. Many of the microfractures present in the surface layer do not persist in deeper layers, therefore, quarrying of large blocks appears possible. However, as with many ultramafic rocks of this type, relief is low and production may require pit quarrying as opposed to bench quarrying.

2. Ordovician Dolomite

Ordovician (Red River Formation) dolomite resources are extensive in the area. Thick, massive, flat-lying and well-exposed beds occur in the area extending from Table and McNally Lakes southwestward to Amisk Lake and Meridian Creek. The dolomite is very dense, crystalline and very fine grained. Its strength and hardness substantially exceed that of the popular Tyndal stone quarried in Manitoba. Colors range from reddish and purplish to tan and mottled combinations of these. The tan variety resembles some of the pale tan dolomites produced and marketed in Italy as marbles.

Fracture pattern studies indicate a fairly well-developed orthogonal system of vertical to nearly vertical fractures. Microfracturing, visible on the surface, largely disappears at shallow depth. Quarrying of blocks adequate for the production of full slabs 2.5 m x 1.5 m x 2.5 m in size appears to be possible. If these dolomites polish as well as their counterparts in the Limestone Lake area they could be classed as "marbles".

Much of the larger size waste generated in a quarrying operation could be used for producing ashlar and rough blocks. Smaller sizes could be crushed for aggregate or ground for the chemical industry.

3. Phantom Lake Granite

Medium- to fine-grained porphyritic pink granite occurs near the southwest shore of Phantom Lake. The pluton is about 1 km wide and 2 km long. Exposures are not abundant and accessibility is somewhat difficult despite its nearness to a road. Surface microfracturing is common but does not appear to penetrate to great depth. A considerable amount of cap rock would have to be removed in a quarrying operation before reasonable sized blocks could be extracted. Although rather ordinary in color and texture, the stone would be of interest to an existing quarry to enhance the variety of its product line.

4. Quartz-Eye Diorite

A small body of quartz-eye diorite about 1.5 km in area occurs near Amisk Lake along the road about 4 km south of Denare Beach. The rock is pink to reddish with bluish quartz eyes and a greenish matrix of hornblende and possibly chlorite. From the few exposures available for examination the rock appears to be sound and attractive although the surface exhibits considerable fracturing. Its uniformity or mineralogical and textural con-

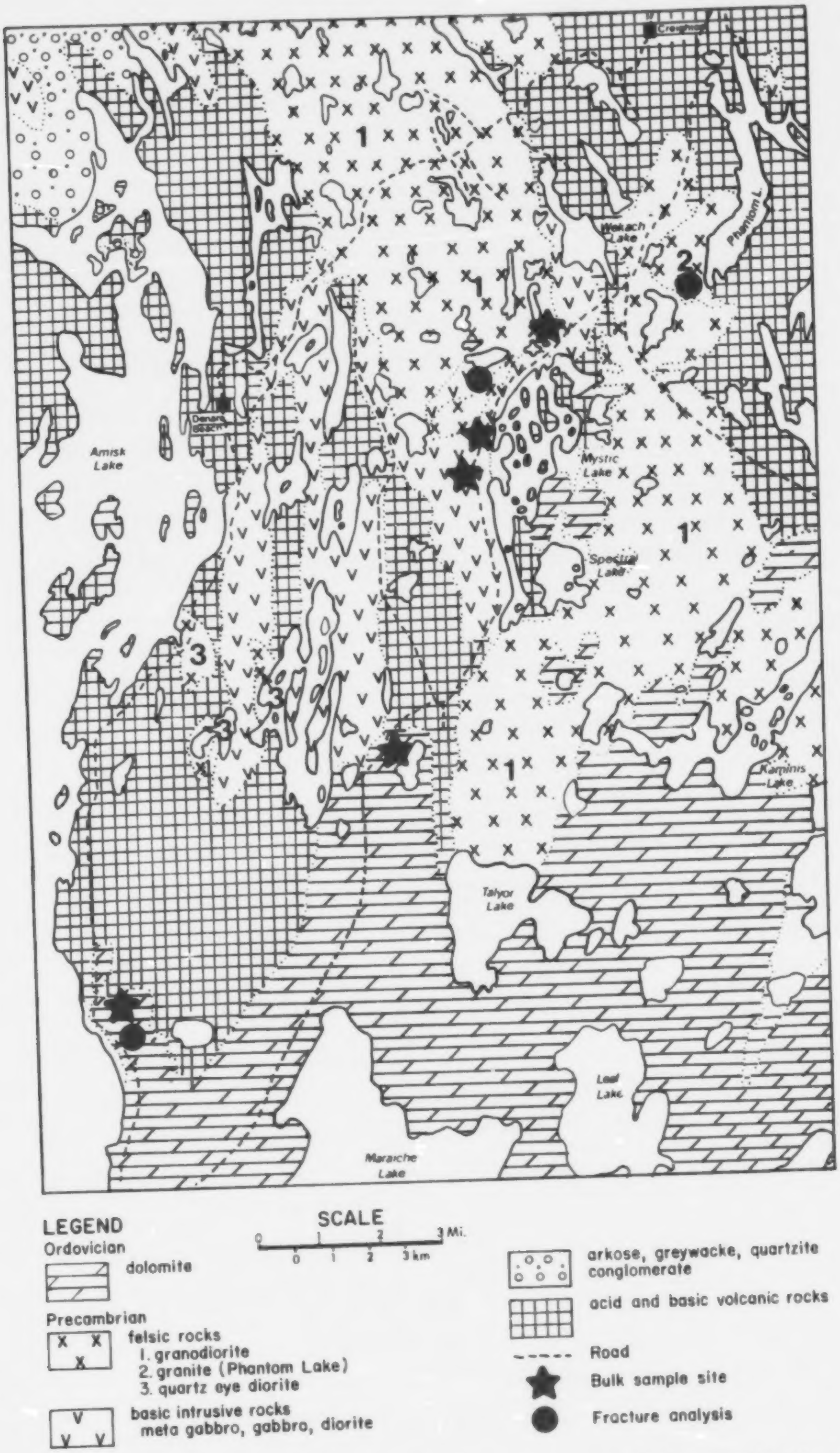

Creighton
Phantom L.
Wekach Lake
Denare Beach
Amisk Lake
Mystic Lake
Spectral Lake
Kaminis Lake
Talyor Lake
Leaf Lake
Maraiche Lake
1
2
3
LEGEND
Ordovician
dolomite
Precambrian
felsic rocks
1. granodiorite
2. granite (Phantom Lake)
3. quartz eye diorite
basic intrusive rocks
meta gabbro, gabbro, diorite
SCALE
0 1 2 3 Mi.
0 1 2 3 km
arkose, greywacke, quartzite conglomerate
acid and basic volcanic rocks
Road
Bulk sample site
Fracture analysis

Figure 1 – Location and general geologic map of the Creighton - Denare Beach area. Geology generalized from Byers et al. (1965) and Byers and Dahlstrom (1954).

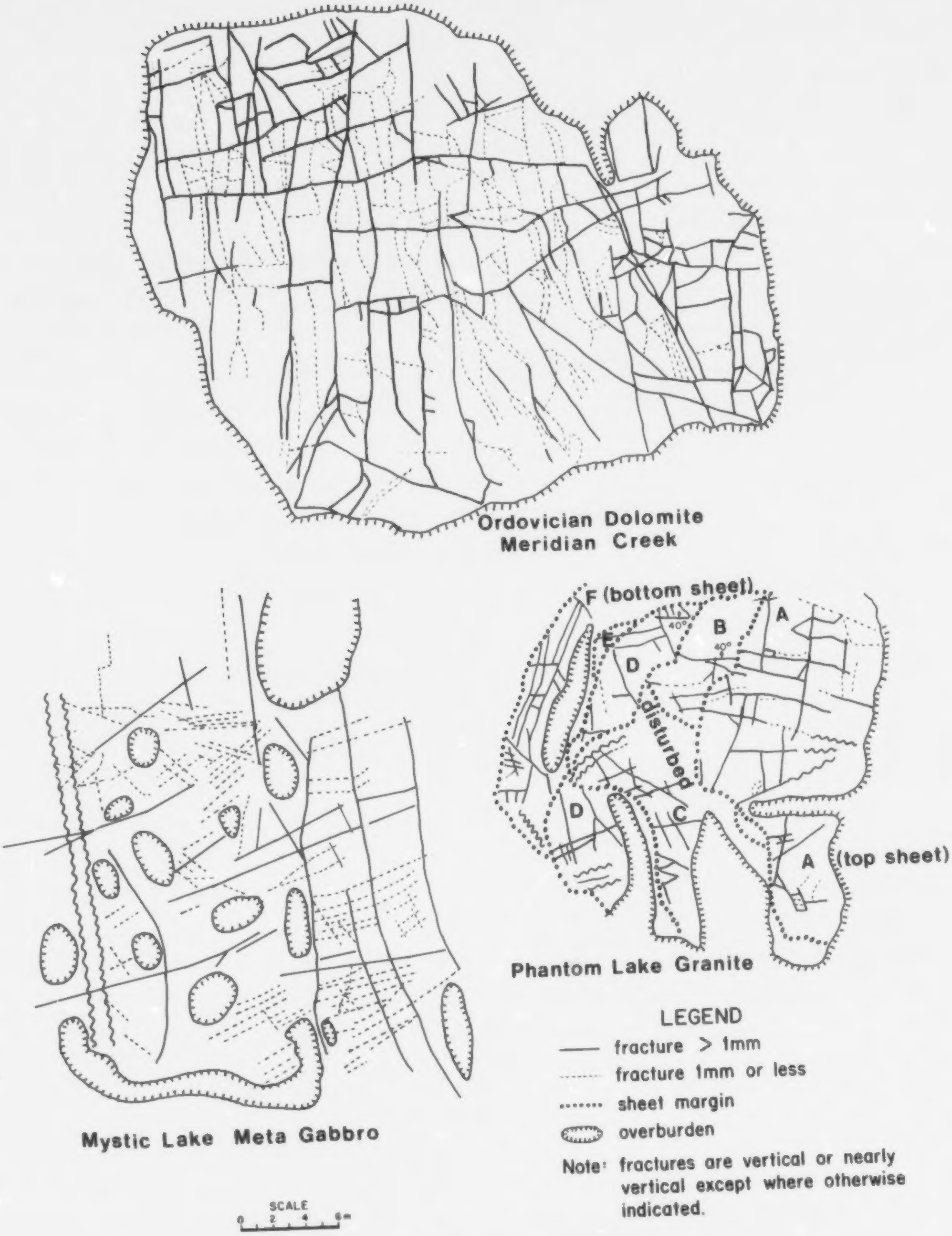

Ordovician Dolomite
Meridian Creek
F (bottom sheet)
E
40°
B
40°
A
D
disturbed
D
C
A
(top sheet)
Phantom Lake Granite
Mystic Lake Meta Gabbro
LEGEND
fracture > 1mm
fracture 1mm or less
sheet margin
overburden
Note: fractures are vertical or nearly vertical except where otherwise indicated.
SCALE
0 2 4 6m

Figure 2 - Fracture patterns in the Creighton-Denare Beach area.

sistency could not be determined due to extensive overburden. Block sizes of 0.5 to 1.0 m are possible. The stone might be suitable for monuments. Considerable stripping is required for further evaluation.

5. Granodiorite

Granodiorite, which is very extensive in the area, is typically medium grained although fine- and coarse-grained and porphyritic phases are also present. Common textural variations include granitoid, foliated and gneissic. Minerals present are typically quartz, feldspar, biotite and hornblende with a variety of minor constituents. Colors range from light and medium grey to pink, orange and brick red.

The few exposures examined exhibit a well-spaced orthogonal fracture system, therefore, quarrying of large blocks is possible. Good positive relief, the proximity of roads and good exposures are positive factors in favor of future development. The stone appears to be of sound quality and is worthy of further investigation.

6. Summary

The Creighton - Denare Beach area is host to several interesting rock varieties which show promise in the dimension stone industry. Of the five rock types examined, dolomite appears to be most readily quarriable, particularly in areas where free faces are available for development of an initial bench. Relatively simple quarrying techniques such as rail-mounted circular, or wire chain saws could be employed in combination with plugs and feathers. The Mystic Lake gabbro and its variants, and the Ordovician dolomites are of particular interest both from the aesthetic perspective and the latter for its versatility and relative ease of development. Both types as well as the granitic rocks in general warrant more detailed evaluation. When adequate resources of suitable quality and block sizes are demonstrated, test quarrying of full size blocks and preparation of polished slabs and other possible products for market testing would be appropriate steps toward development.

7. References

Byers, A.R. and Dahlstrom, C.D.A. (1954): Geology and mineral deposits of the Amisk - Wildnest Lakes area, Saskatchewan; Sask. Dept. Miner. Resour., Rep. 14, 177p.

Byers, A.R., Kirkland, S.J.T. and Pearson, W.J. (1965): Geology and mineral deposits of the Flin Flon area, Saskatchewan; Sask. Dept. Miner. Resour., Rep. 62, 95p.

Three Major Processes that Occur During the Deposition and Preservation of Potash Salts of the Prairie Evaporite in Saskatchewan

D.M. Lane

Lane, D.M. (1989): Three major processes that occur during deposition and preservation of potash salts of the Prairie Evaporite in Saskatchewan; *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

This study examines the general interrelationships of gypsum, anhydrite, carnallite, sylvite and limestone in the Saskatchewan sub-basin of the Middle Devonian Elk Point basin. Its object is to demonstrate the roles played by three major processes in the deposition and preservation of sylvite and carnallite in the basin. These processes are:

1. Dehydration of gypsum to anhydrite,
2. "Brine Pool" conversion of carnallite to sylvite and
3. Ion exchange or chemical reaction of carnallite with limestone of the Dawson Bay and Souris River formations.

Each of these processes is involved in volume reductions in the Prairie Evaporite and the conversion of carnallite to sylvite.

1. Background

A new era of potash mining in Saskatchewan is thought to have commenced in 1989 with the conversion of a conventional underground potash mine to a solution mine, the commercial production of calcium chloride brine from another mine, and the massive injections of calcium chloride into the Dawson Bay Formation to control water inflow into another potash mine. Saskatchewan's conventional underground potash mines are maturing after twenty years of production. The new "era" demands a thorough review of existing geological concepts and data. Applications of these concepts or processes to Saskatchewan Prairie Evaporite sediments may be of benefit to the potash mining industry. Significant impact may also be realized in the petroleum and chemical industries through enhanced industrial diversity.

Considerable new data are available since the comprehensive major regional work on the Prairie Evaporite in Saskatchewan was completed and published by Holter (1969). These data include numerous deep test holes for potash and hydrocarbon exploration that penetrate the entire Prairie Evaporite section.

Sonnenfeld (1984) provides some of the basic elements used in the application of three interrelated processes presented in this report. The work of Shearman (1983) is considered a principal reference for one of the major processes. Brine pool concepts used in the present study have been presented by various authors including Valyashko in Baar 1972 and brine chemistry involving the reaction of Prairie Evaporite carnallites with limestones of the Dawson Bay formation is mentioned in Buchinski (1988).

Anhydrite occurring within the Prairie Evaporite below the potash-bearing members has an aggregate thickness of over 75 m, which would have required deposition of some 121 m of original gypsum. During dehydration of the gypsum some 46 m of subsidence of overlying beds could result, excluding the effects of the released water of hydration.

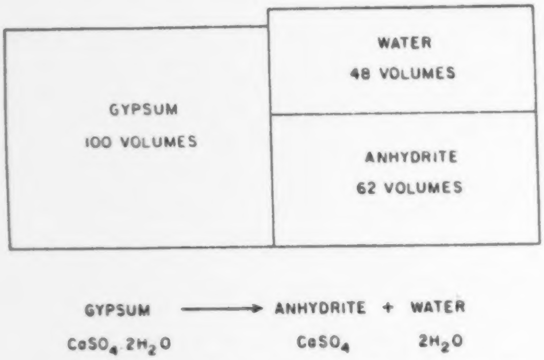


Figure 1 – Illustration of the volume reduction in the dehydration of gypsum to anhydrite.

When carnallite converts to sylvite in brine pools, there is a volume reduction ratio of 4.6:1 and liberation of the water of hydration. Volumetric (thickness) reduction of the Patience Lake Member, involved in the postulated conversion of carnallite to sylvite in the Pacid Allan 4-29-32-28-W2 well, would be about 23 m. Figure 2 shows that, locally, sylvites occur over thick anhydrites in wells 1 and 5 whereas carnallites are predominant over thin anhydrites in well No. 3.

A generalized interpretive model (not shown here) of events related to the conversion of Patience Lake carnallite to sylvite and to the preservation of the sylvinitic beds formed in the Saskatoon potash mining area is presented and defined in a forthcoming report.

High salinity brines occurring in "closed" reservoirs appear to be products of a reaction between carnallites and limestones of the overlying Dawson Bay and Souris River Formations. End products of the reaction include calcium chloride, dolomite and sylvite.

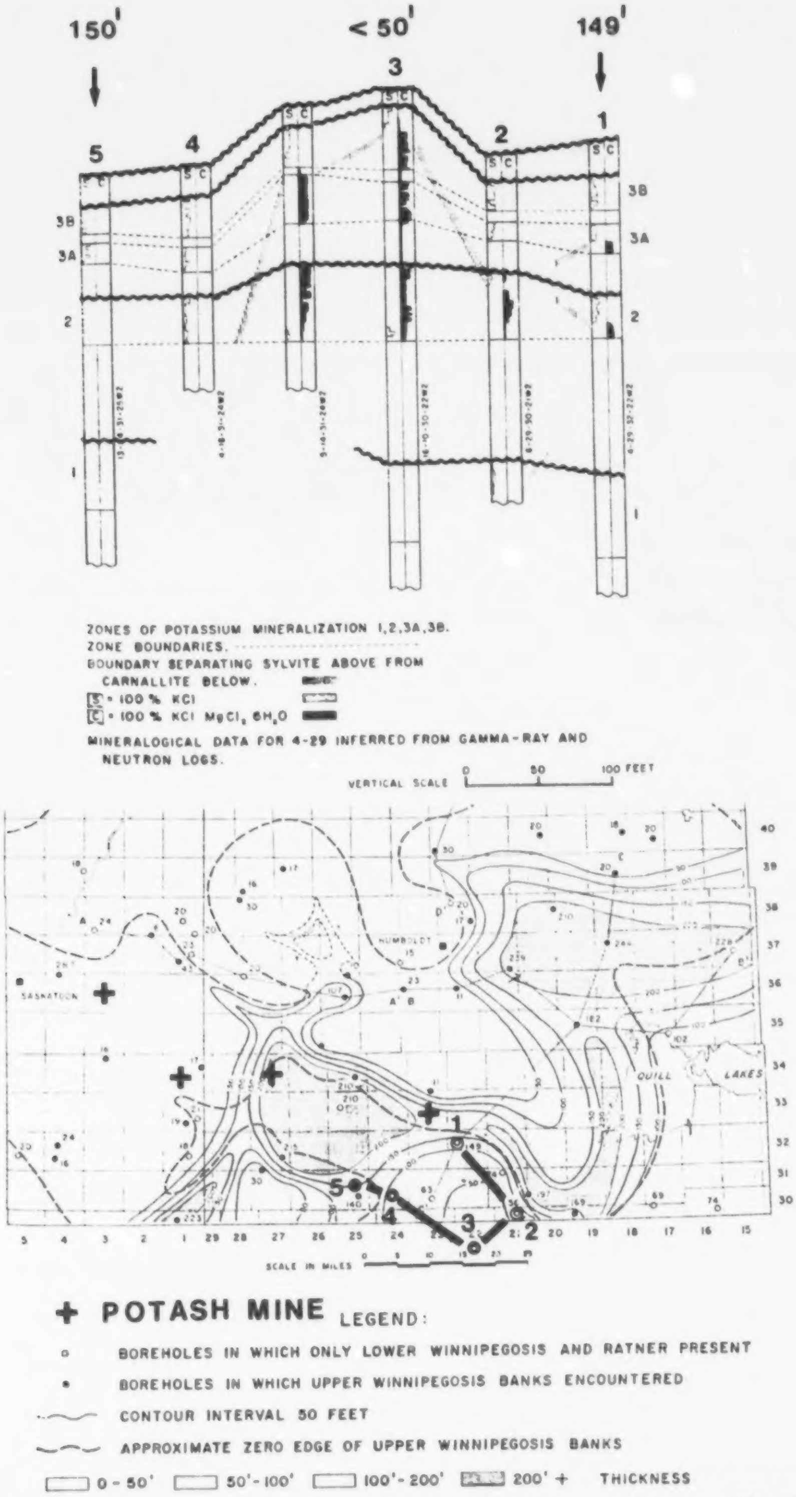

150'
< 50'
149'
5
4
3
2
1
S C
3B
3A
2
1
ZONES OF POTASSIUM MINERALIZATION 1,2,3A,3B.
ZONE BOUNDARIES.
BOUNDARY SEPARATING SYLVITE ABOVE FROM CARNALLITE BELOW.
S = 100 % KCl
C = 100 % KCl MgCl2 6H2O
MINERALOGICAL DATA FOR 4-29 INFERRED FROM GAMMA-RAY AND NEUTRON LOGS.
VERTICAL SCALE 0 50 100 FEET
SASKATOON
HUMBOLDT
QUILL LAKES
SCALE IN MILES
+ POTASH MINE
LEGEND:
BOREHOLES IN WHICH ONLY LOWER WINNIPEGOSIS AND RATNER PRESENT
BOREHOLES IN WHICH UPPER WINNIPEGOSIS BANKS ENCOUNTERED
CONTOUR INTERVAL 50 FEET
APPROXIMATE ZERO EDGE OF UPPER WINNIPEGOSIS BANKS
0 - 50'
50' - 100'
100' - 200'
200' +
THICKNESS

Figure 2 – Cross-section and map showing relationships of thick local anhydrites to sylvinitic or carnallitic areas.

2. Conclusions

1. All potash occurring within the Saskatchewan subbasin of the Elk Point was originally deposited as carnallite.

2. Local subsidence or downwarping of strata overlying the Prairie Evaporite in the potash-bearing areas can be attributed to a combination of the effects of dehydration of gypsum to anhydrite and the conversion of carnallite to sylvite rather than compaction of Winnipegosis lime muds.

3. Subsurface brines from the Winnipegosis, Dawson Bay and Souris River Formations have a high potential for commercial applications such as the reduction of Co_2 from stack gases, production of calcium chloride, calcium chlorate, calcium carbonate (for paper coating) and a variety of other uses. Saskatchewan water analysis data for the Winnipegosis, Dawson Bay and Souris River Formations have been compiled. Salinities (TDS) have been mapped and potentially commercial occurrences of magnesium and calcium brines are identified in a separate study in preparation.

4. The concepts presented in this study should assist in the interpretation of geophysical data for both oil and potash exploration and development.

3. References

Barr, C.A. (1972): Actual geologic problems in Saskatchewan potash mining, Annual Western Meeting of CIM, Saskatoon, 50p, 37 Figures.

Buchinski, K.W. (1988): The occurrence, recovery, and commercial application of calcium chloride brine from a Saskatchewan potash mine; *in* 90th Annual General Meeting, CIM, Saskatoon, 16p

Holter, M.E. (1969): The Middle Devonian Prairie Evaporite of Saskatchewan; Sask. Dep. Miner. Resour., Rep. 123, 134p.

Shearman, D.J. (1983): Syndepositional and late diagenetic alteration of primary gypsum to anhydrite; *in* Sixth Symposium of Salt; The Salt Institute, Alexandria, Virginia, v1, p41-50.

Sonnenfeld, P. (1984): Brines and Evaporites; Academic Press, Inc., Orlando, Florida, 613p.

Kimberlite (Diamond) Studies

Regional Phanerozoic Anomalies of Saskatchewan

Malcolm R. Gent

Gent, M.R. (1989): Regional Phanerozoic anomalies of Saskatchewan; *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

Geologic conditions within the Phanerozoic sedimentary basin of Saskatchewan are considered ideal for the occurrence of economic diamondiferous kimberlites. A number of anomalous structures possibly related to alkalic intrusives including kimberlites have been identified in the Phanerozoic sediments of Saskatchewan. Based upon the limited data available to date, it is tentatively proposed that kimberlites may have intruded near areas where there are major NW- and NNE- to NE-trending basement faults and craton border structures. The NE faulting tends to have a more translational movement than NW-trending faults which appear to have a significant dip slip component.

Although anomalous structures have been identified in scattered areas throughout the sedimentary basin of the province, the only proven alkalic and particularly kimberlitic intrusives identified to date occur in a northeast-trending swath from north-central Montana and southeast Alberta to Prince Albert, Fort a la Corne and probably the Diefenbaker Lake areas of Saskatchewan. Alkalic intrusives at Sturgeon Lake (near Prince Albert), southeast Alberta and Montana are of Late Cretaceous to Eocene age while the Elbow intrusives may be multistaged, being of Devonian and probably Late Cretaceous or younger ages. It is suggested that even Cambrian or older structures in Saskatchewan may also be significant to exploration activities for precious gems.

1. Introduction

The discovery of diamondiferous kimberlites on the north shore of Sturgeon Lake approximately 40 km northwest of Prince Albert has created a considerable amount of interest and speculation in diamond exploration in Saskatchewan on the part of the general public and the mining industry in particular.

The possibility of diamond deposits existing in Saskatchewan is not a recent concept. Mr. John J. Johnson of Flin Flon, Manitoba requested an exclusive exploration license for Saskatchewan in 1948, and in 1961 a staking rush for diamonds in the Prince Albert area occurred after Mr. Pellack filed claims covering a gravel pit in that area. No diamonds were reported to have been mined in either of these cases. The separately reported discoveries of kimberlites by Monopros and Corona Resources in 1988 and 1989 respectively has regenerated interest for diamond exploration in Saskatchewan and to date over 400,000 hectares of land have been claimed under the Mineral Disposition Regulations in the Prince Albert area. Claims under the Mineral Disposition Regulations have been filed for approximately 960 and 13,000 hectares in the Elbow and Val Marie areas respectively. Investigations to date suggest that these areas lie in the region with a potential for occurrences of precious gems.

2. Project Objectives

The models for emplacement of kimberlites in different parts of the world vary widely, and there is as yet no published, universally applicable exploration model for them. To support local exploration activities, an investigation of regional Phanerozoic anomalies in Saskatchewan is being conducted with the objectives of:

1) documenting anomalous conditions which are potentially related to occurrences of kimberlites and related bodies in the region; and
2) attempting to develop a preliminary model and general framework for diamond and other precious gem prospection.

Although there is no universal consensus on the tectonic controls of the distribution of kimberlites, economically exploitable diamond-bearing kimberlites are commonly found in regions underlain by cratons with portions older than 2.4 Ga fused to younger belts of metamorphic rocks >1.0 Ga. Most important kimberlite provinces are also covered by Phanerozoic sediments (Mitchell, 1986). The geologic setting of the Phanerozoic sediments in Saskatchewan is ideal for the occurence of economic diamondiferous kimberlites in that they meet all of the above criteria.

3. Preliminary Investigation Results

a) Methodology

To meet the objectives of this study, public domain well hole; seismic; gravity; photogeologic and other forms of remote sensing data as well as tests of airborne geophysics; remote sensing; geochemical; and field prospection techniques are being applied. Anomalous conditions within the Phanerozoic basin of Saskatchewan presently being studied include the following:

1) Igneous rocks encountered by drill holes within the Phanerozoic sediments.
2) Anomalies within the Phanerozoic sections identified by drilling, stratigraphic mapping, gravity and/or seismic surveys which may indicate post depositional intrusives.

3. Areas with rare occurrences of recent marls similar to those occurring in and along Sturgeon Lake (even though no direct relationship is obvious).

b) Igneous Rocks in the Phanerozoic Basin

With the exception of the kimberlite pipes discovered in the Fort a la Corne and Sturgeon Lake areas, the only other igneous intrusion known in the Phanerozoic sediments of Saskatchewan is a 23 cm long, 10 cm diameter cored section of serpentine reportedly encountered in the Watrous Formation by the Tide Water Signal Morse well (12-17-16-7W3). This core was removed from the Saskatchewan Energy and Mines core collection in the 1960's as it was originally believed to have been misplaced from a basement drill hole intersection. Subsequent investigations have found no public or confidential documentation of such, nor any indication of any other drill hole core stored in the same area of the collection having any indications of being intruded by this rock.

The serpentine is thought to have intruded at 534.3 to 537.3 m BSL as there is an abnormal absence of gypsum and the presence of dusty calcite in this section of the Watrous Formation core. This cored sample has no foliation, but there is a weak parting at 60° to 70° from the core axis along green (more chloritic or serpentine-rich) layers. A single mm wide carbonate vein cuts the core at 30° from the core axis. Also of note is the strong hydroscopic character of the serpentine. Electron probe analysis of the serpentine core by Dr. L.C. Coleman of the University of Saskatchewan has identified it to consist primarily of antigorite and/or chrysotile with carbonates (dolomite and ankerite), euhedral chromite, chlorite and small grains of pentlandite.

The texture of the serpentine and lack of alteration of the pentlandite, considering its occurrence within a highly permeable and strongly oxidized sediment, suggests that this may be a relatively recent intrusion. However, there is no indication as yet that it might be in any way related to a kimberlitic body in the region.

Other alkalic igneous intrusive rocks in the vicinity of southern Saskatchewan occur in southeastern Alberta (Tp.1, Rg.5,8&9; and Tp.2, Rg.9) and in central northern Montana where a number of kimberlites and kimberlitic rocks of late Cretaceous to Eocene age occur along a northeastern trend (Marvin, *et al.*, 1980).

c) Anomalous Stratigraphic and Seismic Structures

A number of localized anomalous stratigraphic and seismic anomalies are reported on Map 1 (Anomalous Phanerozoic Structures of Saskatchewan). Some of these may be the results of salt solution effects but others, such as the Lightning Creek, Elbow and Cypress structures, are known to be of different origins. Many of these features are presently under investigation.

Cypress Area:

Field checking south of Fort Walsh (4-7-29W3) has identified well-developed subhorizontal folding of the Tertiary Ravenscrag Formation. S.H. Whitaker (1976) also reported:

1) an over-thickening of the Milk River - Upper Colorado Group with repetition of section evident in electric logs of oil wells - Shell Albercan Govenlock No. 1 (3-7-1-28-W3) and Shell Albercan Govenlock No. 2 (16-3-1-29-W3). The recognizable zone of deformation in these wells extends from a depth of about 60 m to at least 460 m below surface and there is material present that appears to be derived from depths as great as 800 m.
2) the bedrock encountered in SRC Willow Creek well (NW 13-18-1-29-W3) was badly fractured and harder than the Bearpaw or Judith River Formations are anywhere in the region (drilling penetration rate was more than twice as slow as normal for the area and drilling circulation could not be maintained).
3) deformed sediments of the Upper Cretaceous Bearpaw, Judith River, and Lea Park Formations are exposed along Woodpile Coulee (S4-8-9-1-27-W3) where as, at this location, the depth to the top of the Lea Park Formation would be expected to be about 275 m. Furnival (1946) reported that a highly slickensided zone was present at a depth of 374.9 - 378.0 m in the Imperial Boundary No. 1 well (4-9-1-27-W3) which penetrated the disturbed beds. Furnival assumed that this was a thrust surface.

In view of the intrusions nearby in Montana, these features might be attributable to alkali intrusives such as kimberlites in the very near vicinity.

Elbow Area:

In the Lake Diefenbaker (Elbow) area at least seven anomalously high local seismic structures near the top of the Paleozoic have been identified. Gravity data is available for only the Elbow and Gilroy structures. The Elbow structure is a marked gravity high while the Gilroy is not. DeMille (1960) reported the Devonian carbonate (Birdbear Formation) to "have been severely crushed and to a considerable extent replaced by fragments of carbonate rock displaced upward from the Silurian and Ordovician sections". Analyses (Table 1) of garnets that are abundant in the breccia from the 196.9 to 203.0 m BSL of Imperial Elbow No. 1 well (12-25-23-6-W3) have identified some to be of eclogitic origin and indicate a local Upper Devonian diatreme source. No microdiamonds were encountered in the 400 gm sample which contained in excess of 2,000 garnets. The composition of the garnets is considered to be an unfavourable indicator of the potential of this occurrence for diamonds. Subsequent late Cretaceous or younger disturbance of sediments at this location extends to the Bearpaw Formation which at the Imperial Elbow site is over 185 m above the local level. Analyses of surface samples (Table 2) identifies only one pyrope garnet (a G5 from sample E3) in the four samples taken in this area. Within the general area there are discrete 3-4 km

Table 1 - Analyses of Garnets from Breccia of the Birdbear Formation (Imperial Elbow No. 1 well 12-25-23-6W3).

Grain Sample	*Garnet Class.*[1]	*SiO_2*	*TiO_2*	*Al_2O_3*	*CrO_3*	*FeO*	*MnO*	*MgO*	*CaO*	*Na_2O*	*K_2O*	*NiO*	*Nb_2O_5*	*Cl*
1	G3	40.60	0.00	22.23	0.06	22.15	0.45	12.25	1.94	0.26	0.06	0.00	0.00	0.00
2	G3	40.53	0.06	21.93	0.22	22.46	0.41	12.43	1.58	0.31	0.03	0.00	0.05	0.00
3	G5	39.61	0.00	21.45	0.04	27.20	0.68	9.40	1.26	0.28	0.02	0.00	0.06	0.00
4	G5	39.07	0.03	21.24	0.09	29.54	0.89	7.18	1.71	0.25	0.01	0.00	0.01	0.00
5	G5	39.84	0.09	21.55	0.09	25.89	0.62	10.40	1.07	0.29	0.05	0.00	0.11	0.00
6	G3	40.37	0.07	21.75	0.08	19.66	0.52	11.03	6.17	0.33	0.01	0.00	0.00	0.00
7	G5	39.96	0.01	21.47	0.13	25.65	0.63	10.57	1.19	0.31	0.01	0.00	0.07	0.01
8	ALM	37.92	0.06	20.49	0.03	30.37	6.93	3.43	0.73	0.03	0.01	0.00	0.00	0.00
9	ALM	39.21	0.06	20.68	0.07	23.91	0.89	7.12	7.61	0.33	0.01	0.00	0.06	0.03
10	ALM	39.11	0.08	20.44	0.04	26.42	0.76	6.60	6.21	0.26	0.04	0.00	0.05	0.00
11	UCL[2]	38.20	0.05	19.80	0.07	24.33	0.94	2.19	14.25	0.13	0.03	0.00	0.00	0.00
12	UCL	38.56	0.11	20.30	0.15	21.92	1.23	4.22	13.11	0.23	0.06	0.00	0.11	0.00
13	UCL	38.72	0.03	20.62	0.10	22.03	0.81	4.05	13.46	0.11	0.04	0.00	0.00	0.03
14	ALM	37.60	0.12	19.51	0.10	29.62	0.73	1.41	10.91	0.01	0.00	0.00	0.00	0.00
15	G5	39.29	0.13	21.09	0.03	24.16	0.72	8.13	5.90	0.27	0.06	0.00	0.20	0.01
16	ALM	39.25	0.02	20.88	0.00	24.05	0.68	6.52	8.38	0.20	0.01	0.00	0.00	0.00

[1] Garnet Classification is based upon Dawson, J.B. and Stephens, W.E. (1975, 1976).

[2] UCL = unclassified.

(third lambda) aeromagnetic anomalies of up to 600 gammas.

Lightning Creek Structure:

The Lightning Creek structure was documented by A.C. Kendall (1976) who reported the absence of a projected 54.9 to 57.9 m of Winnipeg Formation and a Red River unit at least 60 m thicker than expected in Imperial Lightning Creek well (16-07-06-32-W1). Paterson (1971) also reported the Deadwood upper contact to be about 30 m higher, and that the formation is 20 m thinner than regional values.

d) Geochemical Investigations

Geochemical (INAA) analyses of well cuttings from the Prince Albert and Elbow areas have been conducted to determine whether groundwater mobilization of elements from kimberlitic or other types of alkalic intrusives could be detected. No direct relationship could be identified between the local occurrence of kimberlite and any of the 34 elements analysed for in the 71 well cutting samples from the Cretaceous Lower Colorado, and Upper Devonian Birdbear Formations. Of the 60 samples of the Lower Colorado Formation (23 samples from the Prince Albert area and 37 regional samples) and 11 samples of the Birdbear Formation (7 samples from the Elbow area and 4 regional samples) an unaccountable tendancy for the occurrence of anomolous gold values (15 ppb max., <5 ppb background) in some samples of both formations from the Elbow and Prince Albert areas and strontium values (8,100 ppb, <500 ppb background) in some of the Birdbear Formation samples from the Elbow area was observed. It is not known if these results are coincidental, but enrichment of the sediments in such elements due to local kimberlite intrusions is not expected.

e) Anomalous Recent Marl Deposits

Post glacial marls are reported to occur in the Sturgeon Lake, Yorkton and La Ronge areas. Although there is no apparent direct relationship between the occurrence of kimberlites and the abundance of marls occurring along and under Sturgeon Lake, the coincidence is unusual.

Ground prospection of the area north of Yorkton did not locate any marls but till samples (see Figure 2) were analysed for garnets (Table 2) with encouraging results. No prospection of the La Ronge area has been conducted as the general area of the marls location was not made available to SEM.

f) Tectonic and Intrusive Structures

It is emphasized that the precise locations and in some cases, the significance of the regional structures within the Phanerozoic sediments of Saskatchewan as plotted on Map 1 are not precisely known. The Meadow Lake Escarpment is an example of a sedimentary structural feature that requires investigation, as it is a major linear feature in evidence during Cambrian to Devonian sedimentation and yet there is no indication of an associated displacement of the basement rocks. Contour mapping of key Phanerozoic Formations to delineate and investigate these structures is being undertaken.

Investigations are underway in the Prince Albert area using airborne SAR (Synthetic Aperture Radar) imagery to map surficial materials and expressions of bedrock structures. At the time this report was prepared, the mission by the Radarsat Project Office of Energy, Mines and Resources Canada to acquire this imagery is scheduled for mid-December and the data should be available shortly.

A preliminary map of basement structures (Map 2) has been prepared by qualitative interpretation of regional 1:1,000,000 - scale gravity data (Energy, Mines and Resources Canada, 1981a to h) and detailed 1:253,440 - scale compilation of gravity data (Saskatchewan Energy and Mines maps G-1 to G-6; Standing, 1971a, b, c and Suryam, 1971a, b, c). The two sets of data are not entirely compatible as they are based upon different reference models and as such, the interpretation has been based upon relative quantitative values and especially their spatial variations. Boundaries between 'lithotectonic' or subcraton areas are approximate and tentative. It is anticipated that a number of major faults may not have been mapped where they follow local gravity trends. Any of these boundaries, as well as the mapped faults, may be major zones of weakness favourable for the intrusion of kimberlites or associated alkalic rocks.

The reported break in the NACP anomaly immediately north of 51° Latitude (Jones, A.G. and Craven, J.A., 1989) might be due to the conductivity anomalies occurring to the north and south of this latitude being either different structures or major litho-tectonic feature(s) now separate them. Although detailed gravity data are not available for some key areas and there is a degree of uncertainty as to the boundaries of some subcraton blocks, there is as yet no evidence in the SEM files known to this author to support Jones' and Craven's (1989) proposal for a NW-trending fault at Latitude 51° displacing the NACP anomaly by 100 to 150 km. Indications to date may imply that basement NW-trending faults have primarily a vertical component whereas the NE-trending faults are probably sinistral.

The anomalies derived from seismic survey compilation data which are plotted on Map 1 are most likely not the results of kimberlitic intrusions. The anomalies are positive topographic features of a subsurface horizon near the top of the Paleozoic whereas kimberlites are reported to produce negative relief features. The plotted anomalies serve to indicate possible tectonic trends for

Table 2 - Analyses of Garnets from Surface Samples.

Grain Sample[2]	*Garnet Class.*[1]	*SiO_2*	*TiO_2*	*Al_2O_3*	*CrO_3*	*FeO*	*MnO*	*MgO*	*CaO*	*Na_2O*	*K_2O*	*NiO*	*Nb_2O_5*	*Cl*
E1-1	ALM	38.99	0.00	20.68	0.03	30.09	0.51	6.65	2.75	0.14	0.03	0.00	0.12	0.02
E1-2	GT	36.66	0.66	18.09	0.15	30.05	4.05	4.11	3.55	0.25	0.10	0.11	0.71	1.52
E3-1	ALM	37.17	0.15	19.96	0.12	33.55	0.45	7.20	1.18	0.13	0.01	0.00	0.05	0.03
E3-2	G5	39.06	0.04	20.66	0.15	28.64	0.51	6.79	3.95	0.18	0.00	0.00	0.01	0.00
E4-1	ALM	37.04	0.15	19.70	0.11	29.47	1.64	3.16	8.55	0.09	0.02	0.00	0.06	0.00
Y1-1	G3	41.49	0.07	22.10	0.14	20.02	0.51	13.94	1.29	0.40	0.05	0.00	0.01	0.00
Y1-2	G9	43.18	0.36	19.68	4.10	6.76	0.32	19.68	5.28	0.46	0.03	0.10	0.04	0.00
Y2-1	GT	38.72	0.27	22.84	0.16	11.43	0.21	0.88	24.38	0.23	0.18	0.28	0.00	0.43
Y4-1	G1	42.86	0.58	19.34	4.21	7.40	0.31	19.01	5.77	0.48	0.03	0.02	0.00	0.00
Y4-2	G11	42.45	0.24	18.97	5.51	7.24	0.35	18.32	6.43	0.41	0.07	0.00	0.00	0.00
Y4-3	G11	42.85	0.35	18.38	6.30	7.25	0.36	18.55	5.48	0.45	0.00	0.02	0.00	0.02
Y4-4	G11	41.62	0.12	17.51	7.43	7.86	0.48	17.49	6.94	0.42	0.05	0.04	0.04	0.00

[1] Garnet Classification is based upon Dawson, J.B. and Stephens, W.E. (1975, 1976).

[2] Samples E1-1 to E4-1 from the Elbow Area (Figure 1).
Samples Y1-1 to Y4-4 from the Yorkton Area (Figure 2).

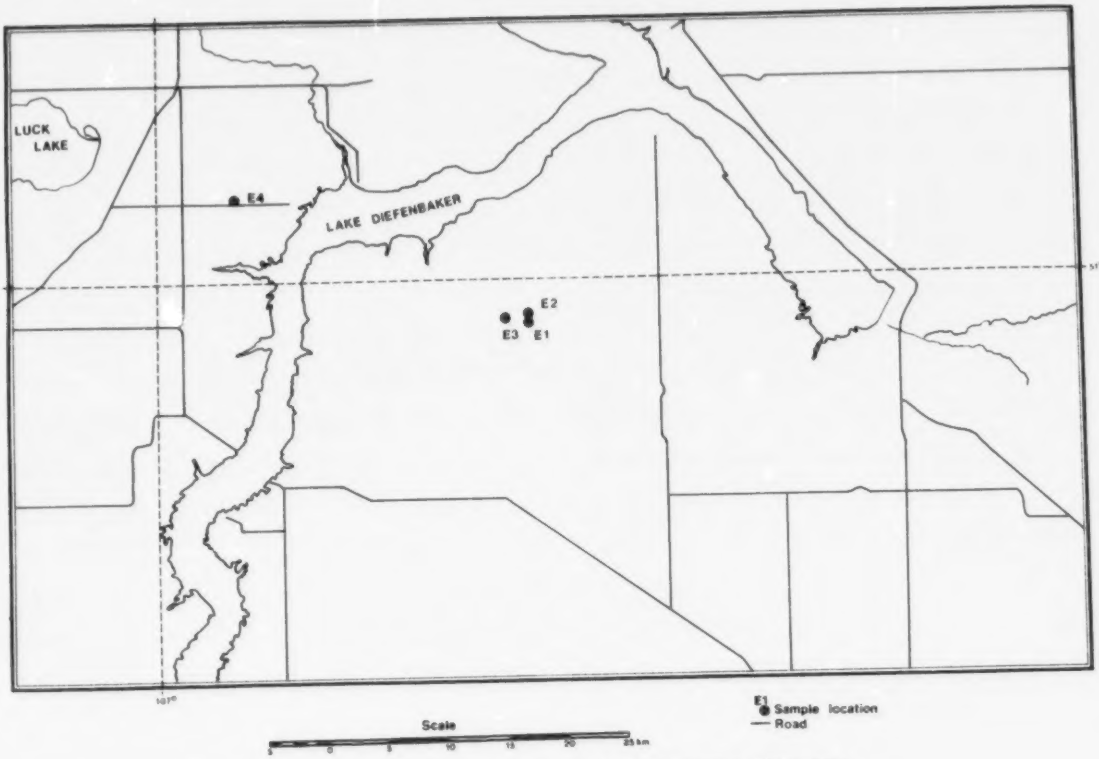

LUCK LAKE
E4
LAKE DIEFENBAKER
51°
E2
E3
E1
107°
Sample location
Road
Scale
5
0
5
10
15
20
25 km

Figure 1 - Location of surface samples analysed for garnets, Elbow area.

kimberlitic or ultramafic alkali intrusions within the Phanerozoic of Saskatchewan.

Stratigraphic investigations have also identified several northeast and northwest structural trends. The sediments, their thickness and facies changes provide strong evidence for northwest-trending structural fluctuations whereas the northeast-trending structures are less evident (Dr. J.E. Christopher, pers. comm.). The northeast trend may be less evident due to the sedimentary isostatic thickness being of the same trend or, more likely, there may be a much larger lateral component to the movement (sinistral) of northeast-trending faults as compared to those to the northwest.

Certainly the anomolous stratigraphic and seismic structures as well as the presence of CO_2 and inert gases (Harper, 1989) in close proximity to the northeast-trending Shaunavon linear is at the very least a remarkable coincidence and at best, a highly suggestive feature.

4. Acknowledgements

The efforts, advice and information of those in industry, Federal, State and Provincial offices are too innumberable to list here. Special mention is due to Keith Richardson (G.S.C. - Exploration Geophysics Subdivision), Roy Slaney (E.M.R. - Radarsat Project Office),

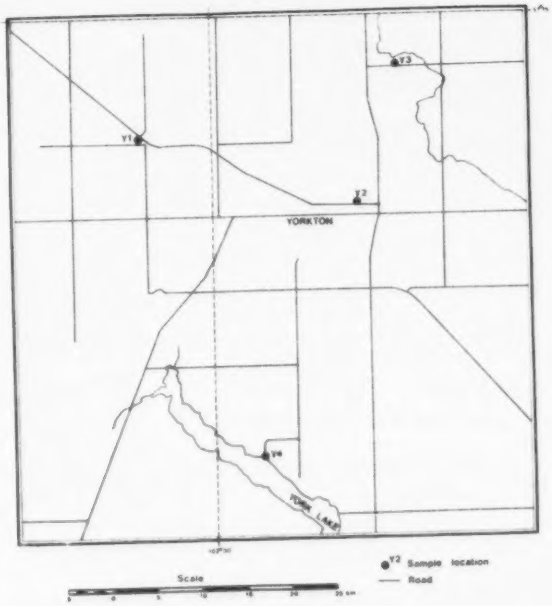

Y1
Y2
Y3
Y4
YORKTON
YORK LAKE
Sample location
Road
Scale
5
0
5
10
15
20
25 km

Figure 2 - Location of surface samples analysed for garnets, Yorkton area.

Mike Thomas (G.S.C. - Lithosphere and Canadian Shield Division), Martin Booth (Saskatchewan Oil & Gas Corporation), Richard Berg (Montana Bureau of Mines), Jim Christopher and the professional and support staff of Saskatchewan Energy and Mines who have done so much to assist with these investigations. However, the author accepts responsibility for any errors in interpretation which in many cases have been based upon tenuous or insuffcent data.

5. References

Collerson, K.D., Van Schmus, R.W., Lewry, J.F. and Bickford, M.E. (1988): Buried Precambrian basement in south-central Saskatchewan: provisional results from Sm-Nd model ages and U-Pb zircon geochronology; *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p142-150.

Dawson, J.B. and Stephens, W.E. (1975): Statistical classification of garnets from kimberlite and associated xenoliths; J. Geol., v83, p589-607.

_________ (1976): Statistical classification of garnets from kimberlite and associated xenoliths - addendum; J. Geol., v84, p495-496.

DeMille, G. (1960): The Elbow Structure of south-central Saskatchewan; J. Alta. Soc. Petrol. Geol., v8, no5, p154-162.

Energy, Mines and Resources Canada (1981a): Gravity Map 48096.

_________ (1981b): Gravity Map 48102.

_________ (1981c): Gravity Map 48108.

_________ (1981d): Gravity Map 52096.

_________ (1981e): Gravity Map 52102.

_________ (1981f): Gravity Map 52108.

_________ (1981g): Gravity Map 56102.

_________ (1981h): Gravity Map 56108.

Furnival, G.M. (1946): Cypress Lake map-area, Saskatchewan; Geol. Surv. Can., Mem. 176, 137p.

Harper, C.T. (1989): Kimberlites in the western Canadian sedimentary basin; *in* Scientific Drilling: Sedimentary Basins; Canadian Continental Drilling Program, Rep. 89-3, p25-26.

Jones, A.G. and Craven, J.A. (1989): The North American Central Plains Conductivity Anomaly and its correlation with gravity, magnetic, seismic, and heat flow data in Saskatchewan, Canada; Geol. Surv. Can. Publ. 42287, 27p.

Kendall, A.C. (1976): The Ordovician carbonate succession (Bighorn Group) of southeastern Saskatchewan; Sask. Miner. Resour., Rep. 180, 185p.

Marvin, R.F., Hearne Jr., B.C., Mehnert, H.H., Naeser, C.W., Zartman, R.E. and Lindsey, D.A. (1980): Late Cretaceous-Paleocene-Eocene igneous activity in north-central Montana; *in* Isochron/West, no29, p5-25.

Mitchell, R.H. (1986): Kimberlites - Mineralogy, Geochemistry, and Petrology; Plenum Press, NY, 442p.

Paterson, D.F. (1971): The stratigraphy of the Winnipeg Formation (Ordovician) of Saskatchewan; Sask. Dep. Miner. Resour., Rep. 140, 57p.

Standing, K.F. (1971a): Gravity Map Series, Yorkton, Map G-3; Sask. Dep. Miner. Resour.

_________ (1971b): Gravity Map Series, Prince Albert, Map G-5; Sask. Dep. Miner. Resour.

_________ (1971c): Gravity Map Series, North Battleford, Map G-6; Sask. Dep. Miner. Resour.

Suryam, J.V. (1971a): Gravity Map Series, Regina, Map G-1; Sask. Dep. Miner. Resour.

_________ (1971b): Gravity Map Series, Swift Current, Map G-2; Sask. Dep. Miner. Resour.

_________ (1971c): Gravity Map Series, Saskatoon, Map G-4; Sask. Dep. Miner. Resour.

Whitaker, S.H. (1976): Geology and groundwater resources of the Cypress area (72-F) Saskatchewan; Sask. Res. Coun., Map 22.

Sm-Nd Isotopic Constraints on the Age of the Buried Basement in Central and Southern Saskatchewan: Implications for Diamond Exploration

K. D. Collerson[1], *J.F. Lewry*[2], *R.W. Van Schmus*[3], *and M.E. Bickford*[3]

Collerson, K.D., Lewry, J.F., Van Schmus, R.W. and Bickford, M.E. (1989): Sm-Nd isotopic constraints on the age of the buried basement in central and southern Saskatchewan: Implications for diamond exploration; in Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

Knowledge of the age of the buried Precambrian basement underlying the southern Plains region of Saskatchewan is critical for tectonic models of the assembly and thermotectonic evolution of the North American Craton during the Early Proterozoic. Determination of the time of crust formation using radiogenic isotopic techniques also has implications for the age of underlying lithospheric mantle. This in turn has a bearing on the thermal history and thickness of mantle lithosphere and consequently, the economic potential of intracratonic potassic igneous suites such as kimberlites and lamproites derived from the mantle. Provisional whole rock Sm-Nd model ages and U-Pb zircon geochronological data for samples from the sub-Phanerozoic basement in Saskatchewan were presented in Collerson *et al.*, (1988). This report contains further Sm-Nd age data for basement cores from central and southern Saskatchewan. These data are interpreted in the context of: 1) established lithotectonic elements in the exposed Shield to the north, 2) U-Pb zircon geochronology, 3) Rb-Sr, Sm-Nd and Pb-Pb isotope systematics in the exposed shield and 4) geophysical data.

1. Geological Summary

The Precambrian basement comprises an assemblage of meta-igneous and metasedimentary rocks of the Superior and Wyoming-Hearne Cratons as well as the southerly extension of the early Proterozoic *ca.* 1800 - 1900 Ma Trans-Hudson Orogen (Hoffman, 1988; Bickford *et al.*, in press; Lewry and Collerson, in press). Lithological descriptions of basement core samples investigated in the current study are given in Collerson *et al.*, (1988) and Collerson and Lewry, (in press). Metamorphic grades range from lower amphibolite to granulite facies. In general, metamorphic domains have a strong north-south elongation. Basement cores from the northwest Plains region are clearly similar in metamorphic grade and lithology to much of the exposed Cree Lake Zone.

Exceptions to the lithological/metamorphic patterns occur: 1) in the Choiceland area, west of the southern extension of the Tabbernor Fault Zone, where there is an abrupt decrease in metamorphic grade and core includes muscovite-biotite-schist, garnetiferous-carbonate-sulphide-bearing schist, phyllite and banded iron formation and 2) in the vicinity of Swift Current where a suite of post-tectonic ca 1760 Ma high-level granites of the Swift Current Anorogenic Province (Collerson *et al.*, 1988), cut variably reworked ortho- and paragneisses.

2. Sm-Nd Isotopic Data

Sm-Nd separation chemistry was carried out at the University of California, Santa Cruz using procedures described in Collerson *et al.*, (1988). Isotope ratios were measured on a seven collector VG 354 Sector thermal ionization mass spectrometer at UCSC, using dynamic multi-collection techniques. Total processing blanks for Nd and Sm were between 40 and 30 pg per dissolution. Duplicate analyses with these digestion techniques agree within analytical uncertainty for both $^{147}Sm/^{144}Nd$ and $^{143}Nd/^{144}Nd$. Fractionation of isotope ratios were corrected using $^{146}Nd/^{144}Nd = 0.7219$. The mean $^{143}Nd/^{144}Nd$ value obtained for 18 analyses of different loads of La Jolla Nd was 0.511853 (relative standard deviation = 6 ppm at the 1 sigma level). The decay constant for ^{147}Sm is $6.54 \times 10^{-12}\ a^{-1}$. Model ages were calculated with respect to a depleted mantle with

$$\varepsilon_{Nd}^{4.6\ Ga} = 0 \text{ and } \varepsilon_{Nd}^{0} = +10$$ (Goldstein *et al.*, 1984).

Sm-Nd isotopic data have now been obtained for 18 basement core samples from three east-west traverses. Samples used in the Collerson *et al.*, (1988) paper were reanalysed, and data for six additional samples have been obtained. Results are summarized in Figures 1 and 2. Present day εNd values range from -19.6 to -33.9 (Figure 1), and reflect the fractional deviation (in parts in 10^4) of the present-day measured $^{143}Nd/^{144}Nd$ ratio from the present day value of CHUR (DePaolo and Wasserburg, 1976). If samples have strongly fractionated REE patterns, εNd values provide a good estimate of the antiquity of the rock (cf. DePaolo and Wasserburg, 1979). To evaluate initial deviations from CHUR at the time of formation of the Trans-Hudson Orogen εNd (t=1870 Ma) values have been calculated (cf., Van

---

(1) Earth Sciences, University of California, Santa Cruz, California
(2) Department of Geology, University of Regina, Regina, Saskatchewan
(3) Department of Geology, University of Kansas, Lawrence, Kansas

Schmus *et al.*, 1987; Bickford *et al.*, 1989). The majority of basement samples have εNd (t=1870 Ma) in the range -2.0 to -13.6. Negative εNd values for the basement gneisses at this time clearly reflect involvement of Archean crust. In contrast, juvenile Proterozoic rocks in the Trans Hudson Orogen exhibit positive εNd values (εNd(t=1870 Ma) of +4.6 to -1.0) that are interpreted to indicate involvement of melts derived from depleted mantle sources (Chauvel *et al.*, 1987). The only basement sample that clearly contains a component of juvenile early Proterozoic material is SASK-11, a biotite-muscovite schist south of the Glennie Domain, with εNd (t=1870 Ma) of +0.6 (Collerson *et al.*, 1988). Granitoids from the Swift Current Anorogenic Province have initial Nd isotopic compositions in the range εNd(t=1760 Ma) of -4.4 to -7.8. These are interpreted as melts of Archean crust.

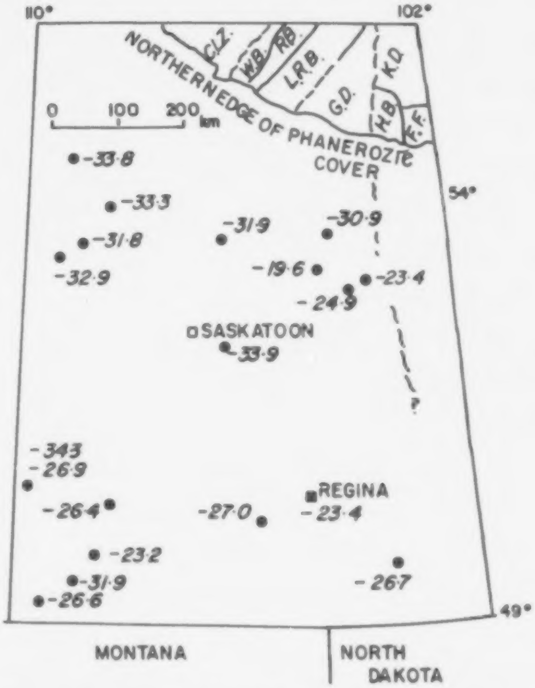

110°
102°
NORTHERN EDGE OF PHANEROZOIC COVER
C.L.Z.
W.B.
R.B.
L.R.B.
G.D.
H.B.
K.D.
F.F.
0
100
200 km
54°
-33·8
-33·3
-31·8
-32·9
-31·9
-30·9
-19·6
-23·4
-24·9
SASKATOON
-33·9
?
-34·3
-26·9
-26·4
-27·0
REGINA
-23·4
-23·2
-31·9
-26·6
-26·7
49°
MONTANA
NORTH DAKOTA

Figure 1 – Map showing εNd (0) values for basement samples. These data give the fractional deviation expressed as parts in 10^4 of the measured ^{143}Nd/^{144}Nd ratio from the present day value of CHUR (cf. DePaolo and Wasserburg, 1976).

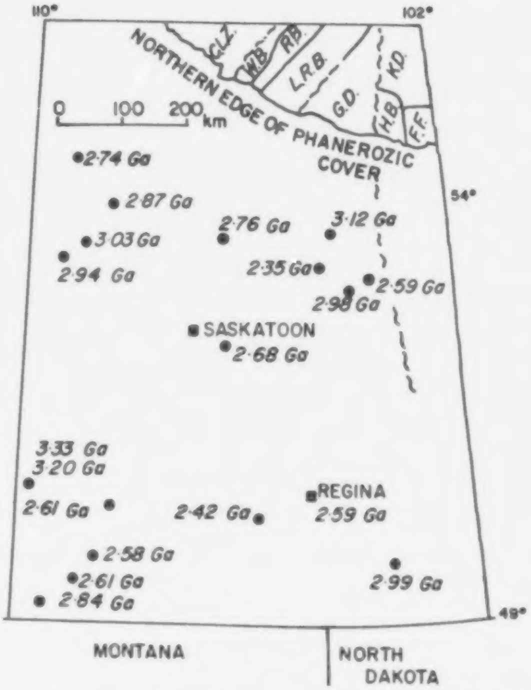

110°
102°
NORTHERN EDGE OF PHANEROZOIC COVER
C.L.Z.
W.B.
R.B.
L.R.B.
G.D.
H.B.
K.D.
F.F.
0
100
200 km
54°
2·74 Ga
2·87 Ga
3·03 Ga
2·94 Ga
2·76 Ga
3·12 Ga
2·35 Ga
2·59 Ga
2·98 Ga
SASKATOON
2·68 Ga
3·33 Ga
3·20 Ga
2·61 Ga
2·42 Ga
REGINA
2·59 Ga
2·58 Ga
2·61 Ga
2·84 Ga
2·99 Ga
49°
MONTANA
NORTH DAKOTA

Figure 2 – Map showing crustal residence Nd model ages for basement samples. These ages are calculated assuming that the crust has separated from a depleted mantle source (cf. Arndt and Goldstein, 1987).

Crust formation ages for rocks with U-Pb zircon ages of 1.7 to 1.9 Ga range from *ca* 3.3 to 2.3 Ga (Figure 2). These Nd model ages give an estimate of the time that has elapsed since a crustal rock had the same ^{143}Nd/^{144}Nd ratio as its mantle source region. The approach assumes that there was only a short time interval between addition of material to the continental crust and fractionation of Sm/Nd during partial melting. Model ages are only valid if the assumptions concerning the source from which the crustal melts are derived are correct (Arndt and Goldstein, 1987). Initial ^{143}Nd/^{144}Nd ratios obtained for mantle derived Archean and Proterozoic suites indicate derivation from light rare earth depleted mantle (DM) source regions with Sm/Nd ratios greater than that of a mantle reservoir with a chondritic Sm/Nd ratio (CHUR). This increase in Sm/Nd in the mantle is considered to be the result of depletion in Nd due to prior crust removal (McCulloch and Compston, 1981). Model ages exhibited by granitoids in the Swift Current Anorogenic Province, *viz.*, 2.40 to 2.60 Ga, reflect fractionation of Nd and Sm during partial melting thereby increasing Nd/Sm (Wilson *et al.*, 1985), and provide minimum estimated ages of the crustal sources of the granites.

3. Discussion

Currently available Sm-Nd isotopic data indicate that:

1) The buried basement in southern and central Saskatchewan contains a significant Archean (Wyoming-Hearne craton) crustal component that was variably affected by Hudsonian thermotectonism during in-

tracratonic collision. Hudsonian U-Pb zircon ages reflect growth of metamorphic zircon and the crystallization of zircon in penecontemporaneous crustal melts derived from Archean crust;

2) Crust of the Archean Superior craton occurs further west than has been previously thought on the basis of geophysical data (cf. Green *et al.*, 1985a and b);
3) Late Hudsonian evolution in the Dakota Segment of the Trans-Hudson Orogen probably involved transcurrent movement in which the arc terrains exposed in the north were dismembered and obliterated (cf. Green *et al.*, 1985a,b). Our data show no evidence for the presence of allochthonous juvenile early Proterozoic crust similar to that exposed in northern Saskatchewan (Lewry and Collerson, in press; Lewry *et al.*, in press; Bickford *et al.*, in press). As a result the estimate by Patchett and Arndt (1986) of the volume of juvenile crust (*ca.* 92 percent) added during formation of the orogen is probably incorrect; and
4) The Swift Current Anorogenic Province formed by partial melting of Archean crust during a late- or post-Hudsonian event *ca.* 1760 Ma ago.

The presence of widespread Archean crust in the buried Precambrian basement places severe constraints on tectonic models for the evolution of the Trans-Hudson Orogen and the extrapolation of lithotectonic elements in the buried basement, based on geophysical data. The widespread occurrence of Archean basement implies that the region is probably underlain by thick, relatively cool Archean lithospheric mantle similar to that represented by xenolith suites in north-central Montana (Hearne *et al.*, 1989).

Tertiary igneous rocks form a major volcanic and plutonic alkaline province in north central Montana (Marvin *et al.*, 1980). One of the largest alkaline centers occurs in the Bearpaw Mountains. In this area, Cretaceous, Jurassic and Mississippian sedimentary rocks overlying Archean basement of the Wyoming Craton form an elongate anticlinal arch that was tectonically active during sedimentation, volcanism and plutonism. Such structures that have been reactivated as a result of epirogenic processes, were clearly important in controlling emplacement of these intracratonic potassic igneous suites in Montana and southern Alberta.

Reactivated Archean and Early Proterozoic basement structures have also been shown by Kent (1987) to have played an important role in controlling Phanerozoic depositional environments within certain parts of the northern Williston Basin. For example, in areas of the basin that are underlain by the Swift Current Platform, and in a zone of presumed epirogenic crustal flexuring lying adjacent to the axis of the maximum thickness of middle Devonian sedimentation in the Prince Albert area.

Emplacement of recently discovered kimberlites in Saskatchewan was probably strongly localized by basement structural features similar to those discussed by Kent (1987). By analogy with other cratons (cf., Mitchell, 1986), and in view of the implied Archean age, as well as the thickness and stability of mantle lithosphere that underlies the Precambrian basement in southern Saskatchewan, kimberlites in this region must be viewed as potentially of economic significance.

4. Acknowledgements

We are grateful to Saskatchewan Energy and Mines (SEM) for financial support through the Canada-Saskatchewan Mineral Development Agreement 1984-1989, when the senior author was a faculty member at the University of Regina, and to D.F. Paterson for assistance locating samples housed in the SEM Subsurface Laboratory in Regina. This research was also supported by National Science Foundation Grants (EAR 87-20442) to Collerson and Bickford and (EAR 83-13167) to Van Schmus and Bickford.

5. References

Arndt, N.T. and Goldstein, S.L. (1987): Use and abuse of crust formation ages; Geology, v15, p893-895.

Bickford, M.E., Collerson, K.D., Lewry, J.F., Van Schmus, W.R. and Chiarenzelli, J.R. (in press): Assembly and reworking of crustal elements during Proterozoic collisional tectonism in the Trans-Hudson Orogen, Saskatchewan: A review; Geology.

Chauvel, C., Arndt, N.T., Kielinzcuk, S. and Thom, A. (1987) Formation of Canadian 1.9 Ga old continental crust 1: Nd isotopic data; Can. J. Earth Sci., v24, p396-406.

Collerson, K.D., Van Schmus, W.R., Lewry, J.F. and Bickford, M.E. (1988): Buried Precambrian basement in south-central Saskatchewan: Provisional results from Sm-Nd model ages and U-Pb zircon geochronology; *in* Summary of Investigations 1988, Sask. Geol. Surv., Misc. Rep. 88-4, p142-151.

Collerson, K.D. and Lewry, J.F. (in press): The buried Precambrian of central and southern Saskatchewan: Implications for diamond exploration; Proceedings of Saskatchewan Geological Society Meeting, Regina, November 1989.

DePaolo D.J. and Wasserburg, G.J. (1976): Nd isotopic variations and petrogenetic models; Geophys. Resear. Let., v3, p249-252.

__________ (1979): Petrogenetic mixing models and Nd-Sr isotopic patterns; Geochim. Cosomchim. Acta, v43, p615-627.

Goldstein, S.L., O'Nions, R.K. and Hamilton, P.J. (1984): A Sm-Nd isotopic study of atmospheric dust and particulates from major river systems; Earth Planet. Sci. Let., v70, p221-236.

Green, A.G., Hajnal, Z. and Weber, W. (1985a): An evolutionary model of the western Churchill Province and western margin of the Superior Province in Canada and the north-central United States; Tectonophysics, v116, p281-322.

Green, A.G., Weber, W. and Hajnal, Z. (1985b): Evolution of Proterozoic terrains beneath the Williston Basin; Geology, v13, p624-628.

Hearne,B.C., Collerson, K.D., MacDonald, R.A. and Upton, B.G.J. (1989): Mantle-crustal lithosphere of north central Montana, U.S.A.: Evidence from xenoliths; Continental Magmatism Abstracts. IAVCEI, New Mexico Bureau Mines Resour. Bull., v131, 125p.

Hoffman, P.F. (1988): United plates of America, the birth of a craton: Early Proterozoic assembly and growth of Laurentia; Annual Reviews, Earth Planet. Sci., v16, p543-603.

Kent, D.M. (1987): Paleotectonic controls on sedimentation in the northern Williston Basin Saskatchewan; Rocky Mountain Assoc. Geol., Symposium, 1987, p45-56.

Lewry, J.F. and Collerson, K.D. (in press): The Trans-Hudson Orogen: Extent, subdivision and problems; *in* Lewry, J.F. and Stauffer, M.R., (eds.), The Early Proterozoic Trans-Hudson Orogen: Lithotectonic Correlations and Evolution; Geol. Assoc. Can., Spec. Pap.

Lewry, J.F., Thomas, D.J., Macdonald, R. and Chiarenzelli, J. (in press): Structural relations in accreted terranes of the Trans-Hudson Orogen, Saskatchewan: Telescoping in a collisional regime? *in* Lewry, J.F. and Stauffer, M.R., (eds.), The Early Proterozoic Trans-Hudson Orogen: Lithotectonic Correlations and Evolution; Geol. Assoc. Can., Spec. Pap.

McCulloch, M.T. and Compston, W. (1981): Sm-Nd age of Kambalda and Kanowna greenstone and heterogeneity in the Archaean mantle; Nature, v294, p322-327.

Marvin, R.F., Hearn, B.C., Mehnert, H.H., Naesser, C.W., Zartman, R.E. and Lindsey, D.A. (1980): Late Cretaceous-Paleocene-Eocene igneous activity in north-central Montana; Isochron West, v29, p5-25.

Mitchell, R.H. (1986): Kimberlites: Mineralogy, Geochemistry and Petrology; Plenum Press, New York. 442p.

Patchett, P.J. and Arndt, N.T. (1986): Nd isotopes and tectonics of 1.9-1.7 Ga crustal genesis; Earth Planet. Sci. Let., v78, p329-338.

Van Schmus, W.R., Bickford, M.E., Lewry, J.F. and Macdonald, R. (1987): U-Pb geochronology of the Trans-Hudson Orogen in northern Saskatchewan; Can. J. Earth Sci., v24, p407-424.

Wilson, M.R., Hamilton, P.J., Fallick, A.E., Aftalion, M. and Michard, A. (1985): Granites and early Proterozoic crustal evolution in Sweden: Evidence from Sm-Nd, U-Pb and O isotope systematics; Earth Planet. Sci. Let., v72, p376-388.

The Sturgeon Lake Kimberlite - An Investigation into the Geochemical Response Exhibited by Organic Sample Media

Colin E. Dunn[1]

Dunn, C.E. (1989): The Sturgeon Lake kimberlite - an investigation into the geochemical response exhibited by organic sample media; *in* Summary of Investigations 1989, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 89-4.

Three aspects of exploration using organic media were examined in the vicinity of the Sturgeon Lake kimberlite body:

a) the diversity and density of the vegetative cover (geobotany);
b) the chemistry of the common plants (biogeochemistry); and
c) the soil bacterial populations, and their resistance to certain 'toxic' metals.

1. Geological Setting

News of the discovery of kimberlitic outcrop in a gravel pit at Sturgeon Lake, 30 km northwest of Prince Albert, became official in November 1988. This discovery was quite unexpected, as no intrusions into the Phanerozoic country rocks, nor indeed any outcrop at all, had been previously reported in the region. The Phanerozoic in the area comprises a 1000 m thick sequence of Cambrian sandstone, Devonian carbonate, Cretaceous sand and shale, capped by Quaternary sand and gravel. Throughout this part of Saskatchewan, Cretaceous shales subcrop beneath a cover of sandy glacial till, locally tens of metres thick.

The kimberlite outcrops as a hard greenish rock, fresh in appearance with few signs of weathering. It is typical of kimberlites in that it is petrographically complex, containing primary crystalline phases and xenoliths of country rock (mainly fragments of baked shale at this occurrence). Minerals that were identified in hand specimen include olivine, pyroxene, dark mica, chrome diopside, ilmenite, and pyrope garnet. Carbonate veining is common. Micro-diamonds are reported from a second kimberlite, discovered in the early summer of 1989 on the Claude Resources property a few kilometres to the northwest.

2. Surveys

The study was conducted during a three day period in late May, 1989, to characterize the response of organic sample media to the presence of the kimberlite, and from this information assess the value of such exploration methods in helping to detect concealed kimberlites.

a) Geobotany

Previous Studies:

Long before the word 'kimberlite' was ever coined, Spix and Martius (1824) claimed to have discovered plant indicators of diamonds in Brazil (see Brooks, 1987, p.109). Subsequently there have been a few accounts of the vegetative cover of kimberlites.

Studies in warm climates have documented that vegetation growth is more luxuriant and more diverse over kimberlite pipes than on the surrounding country rocks. Alexander and Shrivastava (1984) found that over the Hinota pipe in central India the trees were healthier, taller and grew far more densely than those over the surrounding quartz arenite. The difference was attributed to the sharp contrast between the chemistry of the kimberlite and that of the arenite, and in particular to the greater availability of potash, phosphorous, micronutrients and water in the pipe rock.

In the colder climate of the Soviet Union, Buks (1965) outlined the results of a study of eight kimberlite pipes penetrating Cambrian carbonates. Thin larch forest exhibits more profuse growth over the kimberlites than on the surrounding carbonates, and the larches have greater diameter, height and density per hectare.

Sturgeon Lake:

The gravel pit in which the kimberlite was discovered is bordered by moderately dense woodland downslope toward the lake. North and east of the pit are cultivated fields separated by copses of woodland. Only the southern part of the kimberlite outcrop has a cover of trees, thereby providing a limited area for examining the geobotanical expression and testing the biogeochemical methodology.

Trembling aspen (*Populus tremuloides*), 10 - 15 m in height, occurs in stands of moderate density, and is the only common tree. Interspersed are a few balsam poplar (*Populus balsamifera*), rare white spruce (*Picea glauca*) and paper birch (*Betula papyrifera*). Dense shrub growth is dominated by beaked hazelnut (*Corylus cornuta*) and red-osier dogwood (*Cornus stolonifera*). Scattered through the woodland are high-bush cranberry (*Vibumum trilobum*), Saskatoon berries (*Amelanchier*

---

(1) Geological Survey of Canada

alnifolia), flatleaf willow (*Salix planifolia*), prickly rose (*Rosa acicularis*), and a few minor species.

Comparison of the density and diversity of species at Sturgeon Lake with other stands within a radius of 20 km indicated no obvious differences or peculiarities specific to the vicinity of the kimberlite. Unfortunately for this study, most of the vegetation has been stripped from above the kimberlite, and so this conclusion is not definitive. It would be worthwhile to examine remotely-sensed data to see if there are areas of relatively high vegetation density which might be related to kimberlite pipes.

b) Biogeochemistry

The unusual abundance of many trace elements in kimberlite is striking (see Dawson, 1980, p.57). Kimberlites in general are characterized by high contents of: a) elements compatible with ultramafic rocks - Mg, Cr, Ni, Co and b) 'incompatible' elements that are considerably more concentrated than usually found in ultramafic rocks - especially K, P, Zr, Nb, Sr, Ba, Rb, Cs and the light rare-earth elements.

Published biogeochemical data from kimberlites are extremely rare. Ashed samples of a few trees on the Hinota diatreme were analyzed by emission spectrography and data for 10 elements were reported (Mathur and Alexander, 1983). Of the three species analyzed only teak showed some indication of Ni enrichment above the pipe, but concentrations were very low. There was, also, a depletion of Mn over the kimberlite.

As no data were available on the chemistry of the environment around the Sturgeon Lake kimberlite, a small-scale biogeochemical study was initiated to determine if there are significant differences in the chemistry of trees and shrubs growing over the kimberlite from the same species on the surrounding Cretaceous shales. If differences were found to occur, then this information could be used to assist in the discovery of other kimberlite pipes.

Sample Collection:

Vegetation samples were collected along three east-west profiles across and to the south of the kimberlite, and into presumed background areas to the northwest and northeast (Figure 1). A few samples were also obtained from more distant locations.

The plants are growing in gravelly bouldery till up to ten metres or more in thickness, which is overlain by silty brunisol up to 50 cm thick. Exposure of this soil in the gravel pit wall reveals a lower olive brown portion, generally 30 to 40 cm thick, capped by 10 to 20 cm of dark brown to black organic-rich material.

The three most common plants in the area are the aspen, dogwood, and hazelnut. Consequently, twigs (the most recent five years growth) and leaves of each were sampled at all locations (one or another species was absent at a few locations). In addition the top 3 to 5 years growth of aspen stem was obtained by bending the tree over by hand, and cutting (with pruning shears) that portion of the stem ranging from 1 to 2 cm in diameter. In subsequent discussion this is referred to as 'aspen top'. Thus four sample media were collected from most of the 32 sites around the Sturgeon Lake kimberlite, providing 114 twig and stem samples. Five leaf samples from each species were analyzed to establish a comparative database of their element concentrations with respect to the twigs. A few samples were collected from woodland 15 km to the east, to obtain a regional estimate of the consistency of element concentrations in the same species.

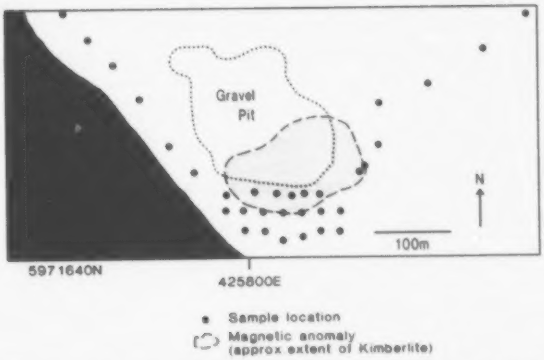


Figure 1 – Location of samples with respect to kimberlite outcrop and UTM coordinates. Land subdivision location; Sec.17, Tp.15, R1, W3.

Sample Preparation and Analysis:

All samples were air-dried for several weeks. Leaves were separated from twigs, and all twig and a few leaf samples were ashed in a kiln at 470°C for 24 hours. A sample of about 0.5 to 1.0 gm of each ash was submitted for 35 element instrumental neutron activation (INAA) analysis at Activation Laboratories, Ltd., Brantford, Ontario. In addition a new technique, developed recently at the Geological Survey of Canada, was used to determine low concentrations of Mo, Ta, and Hf, and also V, Zr and Nb which were not included in the INAA package. This suite of elements was selected because of the unusual abundance in kimberlites of Nb and Ta in particular. Details of the methodology, using inductively coupled plasma/mass spectrometry are soon to be published (Hall *et al.*, in press).

Analytical Results:

Table 1 summarizes element concentrations in each sample medium. Average concentrations are given, which proved to be similar to the median values, thereby attesting to the approximate normal distribution of each element. The notable exceptions are Rb in all sample media, and Ni in dogwood twigs. Data in Table 1 serve as baseline information, since no detailed trace element analyses of these species are recorded in the

Table 1 - Average Element Concentration in Ashed Plant Tissues - Sturgeon Lake and Background Area 15 km to the East.

		STURGEON LAKE							BACKGROUND	
		ASPEN			DOGWOOD		HAZELNUT		ASPEN Tops n = 9	HAZELNUT Twigs n = 11
		Tops n = 31	Twigs n = 29	Leaves n = 5	Twigs n = 24	Leaves n = 5	Twigs n = 28	Leaves n = 5		
Au	ppb	<5	<5	10	10	16	8	17	<5	7
As	ppm	1.3	1.0	1.5	1.1	1.5	8.3	3.9	1.7	12
Ba	ppm	519	436	92	609	142	528	164	1075	1212
Br	ppm	6.6	6.4	15	11	21	11	19	6.5	13
Ca	%	25.0	24.3	14.5	25.3	22.8	24.7	15.0	23.1	23.2
Co	ppm	2.4	1.8	3.2	1.0	1.0	2.0	1.4	2.6	2.4
Cr	ppm	3.6	3.5	8.2	7.0	11	12	38	2.3	8.5
Fe	ppm	800	840	960	1550	1920	2060	2960	810	2263
K	%	10.3	12.2	30.3	8.4	12.1	11.6	18.3	12.1	12.0
La	ppm	0.9	1.1	0.7	1.7	2.2	2.8	3.3	1.1	3.2
Mo	ppm	<2	<2	<2	<2	<2	5.2	6.6	<2	2.3
Na	ppm	417	534	466	960	1161	1237	1600	480	1395
Rb	ppm	31	39	67	17	21	33	60	38	22
Sr	ppm	1104	977	684	1193	762	1000	554	922	85
Th	ppm	0.2	0.2	<0.1	0.3	0.5	0.5	0.6	0.2	0.4
Zn	ppm	2413	1897	1940	712	448	639	520	2989	657

world literature. Other elements for which INAA data were obtained have concentrations close to detection limits in most samples. These elements, with detection limits in ppm in parentheses, are: Ag (2), Cs (0.5), Hf (0.5), Hg (1), Ir (0.002), Sb (0.1), Sc (0.1), Se (2), Ta (0.5), U (0.1), W (1), Ce (3), Nd (5), Sm (0.1), Eu (0.02), Tb (0.5), Yb (0.05), Lu (0.05).

The concentrations found are not unusual for vegetation in general; however, there are some interesting features of the data set:

1. The three species studied have consistently higher concentrations of Ba, Ca, and Sr in the twigs than in the leaves. Most other elements listed in the Table are more enriched in the leaves. Whereas this pattern is normal for deciduous species, the reverse is the norm for conifers.
2. Trace element levels in the aspen are low. In comparison to aspen from an area of Precambrian metavolcanics 40 km north of La Ronge, the aspen at Sturgeon Lake are markedly depleted in Ba, Br, Co, Fe, Na, and Rb.
3. Twigs from each species have broadly similar concentrations of elements, except for the hazelnuts which have higher levels of As (especially the twigs), Cr, Fe, REE, Mo, Na, and Th. The same pattern holds true for the leaves. This suite of elements is related to the relatively high iron content of the hazelnuts.
4. In the 'background' area the only significant difference in chemistry is higher Ba and lower Sr content than at Sturgeon Lake.

Preliminary data obtained for the six elements analyzed by wet chemical methods, indicate that Nb, Ta, and Hf are present at sub-ppm levels; Mo is mostly in ppm concentrations; and Zr and V generally range from 5 - 20 ppm. Niobium is slightly more concentrated in hazelnut than in the other species, and is perhaps derived from weathering of perovskite $(Ca, Na, Fe, Ce)(Ti, Nb)0_3$, a common constituent of kimberlites.

Spatial Distribution of Elements:

Of the 38 elements determined in the seven sample media, only Ni, Sr and Rb exhibit a marked spatial relationship to the location of the kimberlite. The INAA method employed has a detection limit of 50 ppm for Ni, and most samples yielded concentrations below this limit. A notable exception is the dogwood, which has a consistently higher Ni content in twigs from close to the southern margin of the kimberlite (Figure 2).

Even more striking is the relative enrichment of Rb in all three plant species from sites on the kimberlite southward to Sturgeon Lake (Figure 3). The absolute numbers are not significant, because Rb is commonly present at levels of hundreds of ppm in ashed tree tissues; however, the sharp contrast between concentrations close to the kimberlite and those over the

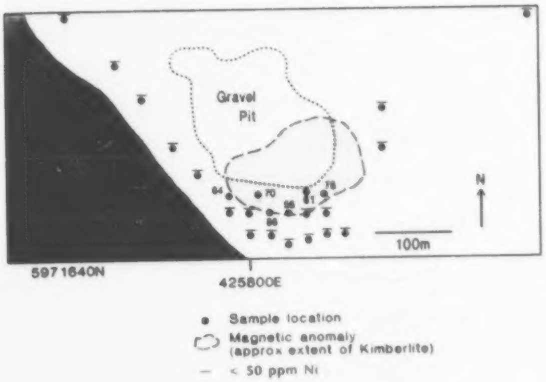


Figure 2 - Nickel (ppm) in ash of dogwood twigs.

Cretaceous is significant. Rubidium is an alkali metal which is extremely soluble, especially as a carbonate, and enrichment in the phlogopite of kimberlite has been recorded (Dawson, 1980). If, therefore, Rb is mobilized from the kimberlite as a carbonate during weathering (or groundwater flow), it would be transported in solution until it becomes absorbed by plants in the acidic environment around their roots, and then translocated up into the aerial parts.

Cesium, too, is an alkali metal that is usually abundant in kimberlites, but Cs enrichment above the detection level of 0.5 ppm occurs in only a few samples, suggesting that Cs is deficient in the Sturgeon Lake kimberlite.

Strontium occurs at much higher levels than Rb, but concentrations of the order found here are not unusual. Again, it is the pattern of relative enrichment which is significant: Sr distribution closely mimics that of Rb. Strontium is an alkaline earth element which has strong chemical affinities to the more abundant alkaline earths, Ca and Mg, and is probably derived mainly from the carbonatization that was associated with the intrusion of the kimberlite. Calcium variation in the plant tissues is not apparent, because Ca is an essential cell-building element that commonly comprises over 20 percent of the ashed twig and therefore small changes related to Ca in the substrate would not be evident.

Recognition of relative enrichment of Rb and Sr in vegetation may possibly assist in detecting kimberlites at shallow depth, especially if there is any upward movement of groundwaters. It is the *relative* concentrations that may be of significance; however, not the absolute values.

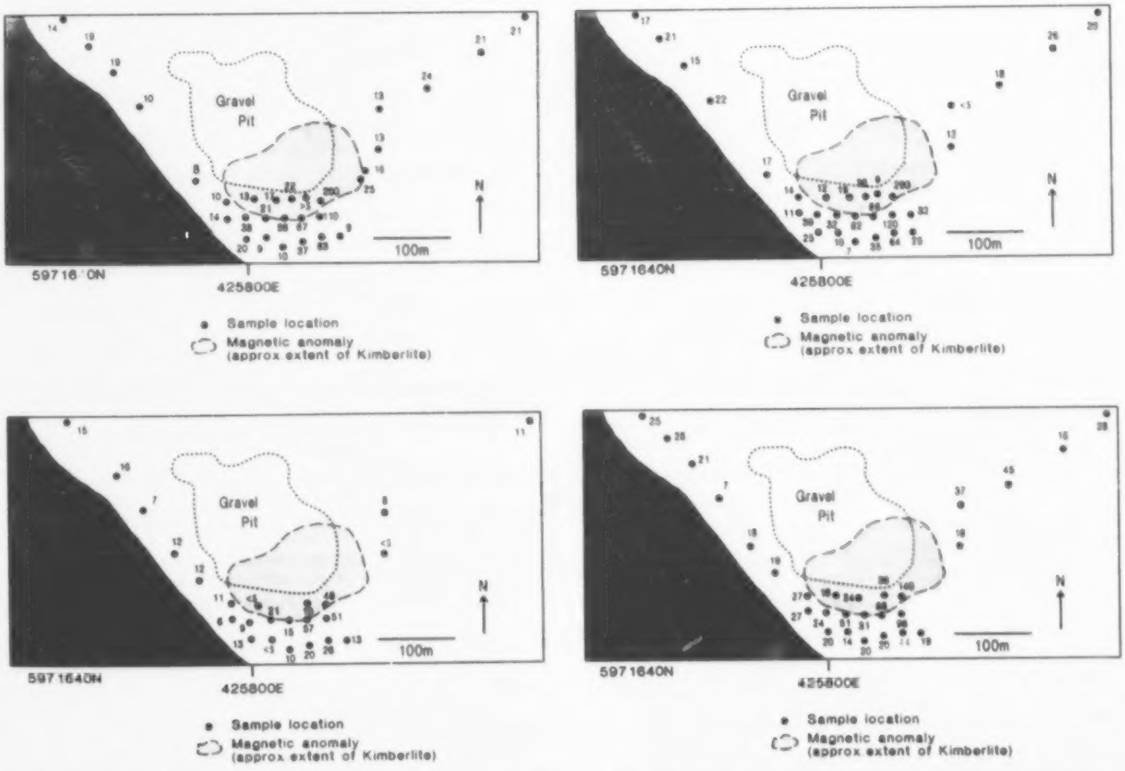


Figure 3 - Rubidium (ppm) in various plant parts: a) in ash of aspen tops; b) in ash of aspen twigs; c) in ash of dogwood twigs and d) in ash of hazelnut twigs.

c) Microbiological Investigations

In recent years two microbiological methods of exploration have been developed. Both rely on the principle that bacterial populations of soils change in the presence of 'toxic' or heavy metals.

Two sets of organic-rich A-horizon soil from a depth of 10 cm were collected at each vegetation site. A trowel was sterilized by dowsing in methyl alcohol and flaming prior to digging each pit, thereby ensuring that no inter-site contamination of bacteria took place. This procedure was recommended for one procedure, but was not considered necessary for the other (involving *Bacillus cereus* population counts). Although data evaluation is not complete, some preliminary observations can be made.

Bacillus cereus Study:

This technique involves population counts of spores of the common soil bacterium Bacillus cereus (Parduhn and Watterson, 1984). Samples were submitted for assay at Cereus Exploration Technologies Inc., Nevada. The data indicate an inverse relationship between bacterial populations and elements in the soil that are of mafic affinity and characteristic of kimberlites.

Metal Tolerance of the Total Bacterial Population:

This method involves the measurement by luminometry of the total bacterial population of the soil (Michaels and Riese, 1986). Nickel and Cr are two of the metals characteristic of kimberlite which are toxic to bacteria. In an environment where these metals are present, bacteria can develop a tolerance to them: if the bacteria are removed from their natural environment and are subjected to solutions containing Ni and Cr, they will survive (or show a certain degree of tolerance) if they have become used to the presence of these elements, or die if they have not. By measuring the percentage that survive the element doping, it is possible to assess if the sample has come from a metal-rich (in this case kimberlite), or a metal-poor area (i.e. Cretaceous shale).

Samples were submitted for analysis to Dr. G. Michaels, Western State College of Colorado, Gunnison, Colorado. Results show a relative tolerance to either Ni or Cr (with a survival rate of greater than 70 percent after adding 100 ppm solutions of these elements) around the southern margin of the kimberlite, and for about 100 m to the east and west of its margin. Tolerance to both elements is observed at eight sites close to the margin.

3. Summary and Conclusions

1) **Geobotany** - The geobotanical study did not identify any features of the vegetative cover which might assist in detecting concealed kimberlites. However, since only a small portion of the kimberlite has not been stripped of vegetation, a conclusive statement cannot be made. Any area that appears to have unusually luxuriant vegetation, which has dimensions appropriate for a kimberlite pipe, should receive careful examination.

2) **Biogeochemistry** - A study of 38 elements in various tissues of trembling aspen, dogwood, and hazelnut generally showed typical levels for deciduous species. The hazelnut has higher concentrations of Fe-related elements (As, Cr, Mo, Na, REE, Th) than the other species. Of possible relevance to biogeochemical prospecting for kimberlites in this environment, are the patterns of Ni, Rb, and Sr distribution. Along the southern margin of the kimberlite, Ni is enriched in dogwood twigs. Strontium, and particularly Rb are concentrated in twigs of the three species at and south of the kimberlite. The Sr is probably derived from the carbonates associated with the kimberlite. Rubidium probably occurs in phlogopite, and goes into solution as the highly soluble carbonate ($RbCO_3$), to be transported until it is absorbed through plant roots, providing a halo of enrichment around and above a kimberlite that may be concealed by sediments.

3) **Microbiology** - Investigations by two techniques suggest an influence of Ni and Cr on the microbial populations of the A-horizon soils. It appears that in the presence of these elements there are relatively low microbial populations, but the bacteria present seem, too, to have developed a tolerance to these 'toxic' elements.

4. Acknowledgements

I thank Monopros Ltd. for their assistance; for supplying me with base maps and information on the kimberlite occurrence; for permission to work on their claim block, and for permitting me to release their data on the microbiological studies. I thank, too, the Saskatchewan Geological Survey for their advice and co-operation, and in particular Pam Schwann (resident geologist in La Ronge) for her competent field assistance. Thanks, too, to employees of the Geological Survey of Canada in Ottawa: G.E.M. Hall and J.-C. Pelchat for wet chemical analysis, R. Dillon for sample preparation, and W. Spirito for data analysis. Except for the microbiological studies, this project was funded by the Geological Survey of Canada.

5. References

Alexander, P.O. and Shrivastava, V.K. (1984): Geobotanical expression of a blind kimberlite pipe, Central India; *in* Kimberlites, I. Kimberlites and Related Rocks; Kornprobst J., (ed.), Proceedings of the Third International Kimberlite Conference, Vol.1, Elsevier, Amsterdam, p33-40.

Brooks, R.R. (1987): Serpentine and Its Vegetation: A Multidisciplinary Approach; Discorides Press, Portland, Oregon, 454p.

Buks, I.I. (1965): The use of the geobotanical method in the search for kimberlite tubes in the Yakutian polar region; *in* Chrikishev A.G. (ed.), Plant Indicators of Soils, Rocks, and Subsurface Waters; Consultants Bureau, New York, p173-175.

Dawson, J.B. (1980): Kimberlites and Their Xenoliths; Springer-Verlag, Berlin, 252p.

Hall, G.E.M., Pelchat, J.C. and Loop, J. (in press): Determination of zirconium, niobium, hafnium and tantalum at low levels in geological materials by inductively coupled plasma mass spectrometry; J. Anal. At. Spectrom.

Mathur, S.M. and Alexander, P.O. (1983): Preliminary pedogeochemical and biogeochemical studies on the Hinota kimberlite, Panna District, MP; Proc. Indian Acad. Sci. (Earth Planet Sci.), v92, no.1, p81-88.

Michaels, G.B. and Riese, W.C. (1986): Microbiological exploration for mineral deposits: a new technique; Applied Geochem., v1., p103-109.

Parduhn, N.L. and Watterson, J.R. (1984): Preliminary studies of *Bacillus cereus* distribution near a gold vein and a disseminated gold deposit; U.S. Geol. Surv., Open File Rep. 84-0509, 8p.

Spix, J.B. von and Martius, C.F. (1824): Travels in Brazil in the years 1817-1820 undertaken by command of His Majesty the King of Bavaria; Longmans, London.

Appendices

Abstracts of Recent Saskatchewan Energy and Mines Publications and Papers by Staff of the Saskatchewan Geological Survey

---

Eckstrand, O.R., Grinenko, L.N., Krouse, H.R., Paktunc, A.D., Schwann, P.L and Scoates, R.F.J., (1989): Preliminary data on sulphur isotopes and Se/S ratios, and the source of sulphur in magmatic sulphides from the Fox River Sill, Molson Dykes, and Thompson nickel deposits, northern Manitoba; in Current Research, Part C, Geol. Surv. Can., Pap. 89-1C, p235-242.

Sulphides from three mafic-ultramafic suites of the Circum-Superior Belt in northern Manitoba contrast markedly in their sulphur isotope and Se/S ratios, and thus indicate different sources of sulphur. Sulphur isotope values of the Fox River Sill disseminated sulphides average about +9 per mil, clearly indicating a crustal source, but that source is not sulphide iron-formation (-0.3 per mil) stratigraphically lower in the sequence. The wide range of $\delta^{34}S$ values (0.7 to 17.4 per mil) and Se/S ratios suggests mixing of sulphur from more than one source.

Sulphur isotope ratios of sparsely disseminated sulphides in the Molson Dykes lie near mantle values, and may point to a mantle source. Se/S ratios show much scatter, greatly exceeding the mantle range.

Nickel sulphide ores of the Thompson Nickel Belt have tightly clustered $\delta^{34}S$ ratios (+4 per mil), the same as barren wallrock sulphides. Se/S ratios of the ores overlap those of barren sulphides, but extend about halfway toward mantle values, suggesting that mantle sulphur in the original magma was massively contaminated by wallrock sulphides to form the nickel sulphide ores.

Harper, C.T. (1989a): Kimberlites in the western Canadian sedimentary basin; in Scientific Drilling: Sedimentary Basins; Canadian Continental Drilling Program, Rep. 89-3, p25-26, Kimberlites in the Western Canadian Sedimentary Basin.

Although unsubstantiated claims of diamond discoveries in north-central Saskatchewan had been made previously in 1948 and 1961, the recent news reports of kimberlitic pipes being discovered in the Prince Albert area still came as a surprise to many people. The fact that Monopros Limited, a Canadian subsidiary of DeBeers Mining Company of South Africa, was actively exploring a property at Sturgeon Lake, northwest of Prince Albert, lent credence to the rumours and has fueled a staking rush now exceeding 332,000 hectares (700,000 acres). Kimberlites usually occur in clusters and there have been unsubstantiated reports of other pipes being located in the region.

The most common tectonic environment for kimberlites is within stable platforms of continental areas, with intrusion occuring during epeirogenic movements (uplift or dilation) of the platform, particularly along deep-seated fractures. The Sturgeon Lake kimberlitic pipe intrudes Cretaceous strata and outcrops in a gravel pit at or near the surface. The location of the pipe is near the zone of intersection of the North American Central Plains Conductivity Anomaly and the Sweetgrass - North Battleford Arch (Figure 1). *Is this a controlling factor for the emplacement of the pipes and are there other basement structures which could have influenced intrusion of these ultramafic rocks?*

A distinctive alkalic igneous petrographic province occurs in central Montana. The late Cretaceous to Eocene igneous rocks occur as sills, laccoliths, stocks, dikes, diatremes and volcanics. Some of the diatremes have been identified as kimberlites, e.g. the Williams kimberlite in the Little Rocky Mountains area and some of the dykes, such as the Yogo lamprophyre, contain sapphires. A cluster of alkalic intrusions also occur near the crest of the Sweetgrass Arch just south of the international border. Most of the central Montana intrusions yield radiometric ages of 44 to 54 Ma. *By inference could the Sturgeon Lake intrusive belong to this petrographic province and be of a similar age? In conjunction with this, what is the possibility of the existence of unknown clusters of alkalic igneous intrusions along the drift covered extension of the Sweetgrass - North Battleford Arch? What is the significance of an unusual structure south of Elbow, Saskatchewan, which has an apparent post-Cretaceous age and has been variously attributed to cryptovolcanic, meteor impact, salt intrusion and/or solution and thrust faulting processes?*

Gas wells in the vicinity of the Sweetgrass-Arch cluster of intrusions contain high levels of CO_2 in association with nitrogen, helium and other rare gases. It has been suggested that the formation of the gases is genetically linked to these intrusions. Similar gas-enriched wells define a northeasterly trend from the southwestern corner of Saskatchewan to a point 95 km south of Prince Albert, subparallel to both the Sweetgrass - North Battleford Arch and the Shaunavon Linear. Gas-rich inclusions in diamonds commonly contain high levels of nitrogen and CO_2 and kimberlites themselves are commonly rich in carbonate. *Is it a coincidence that marls have formed and are still forming at Sturgeon Lake? Can the presence of CO_2, nitrogen and other inert gases be used as an exploration guide in locating unexposed diatremes of kimberlitic affinity?*

Answers to some of these questions could be obtained through the coordinated efforts of researchers involved in the Canadian Continental Drilling Programme. While the present emphasis is on elucidation of deep-seated basement structures and their role in trapping petroleum resources (and providing loci for kimberlite intrusions?), there is obviously still a need for investigations of a shallower nature. Perhaps the diamond staking rush will provide the impetus for further research in the western Canadian sedimentary basin.

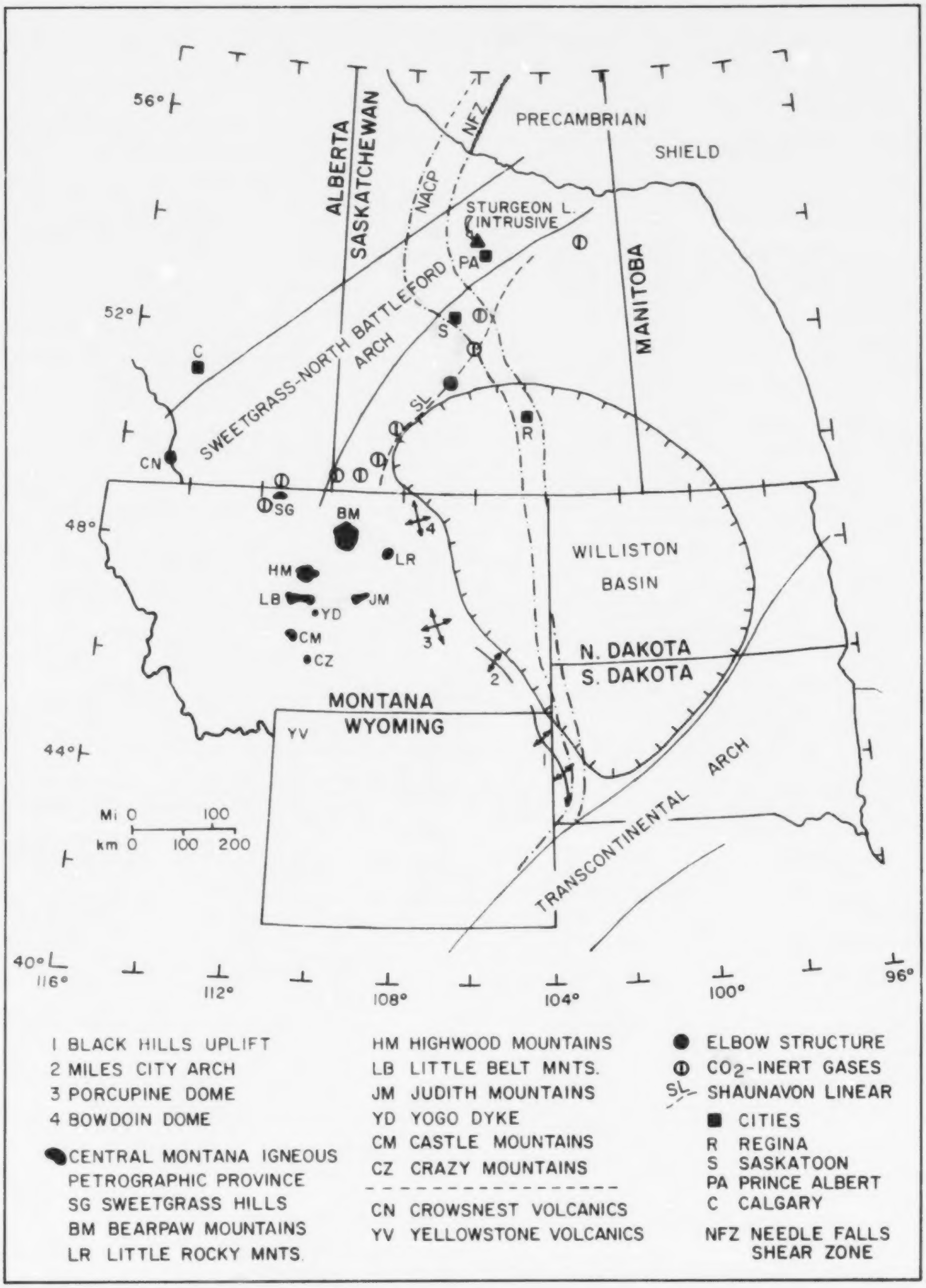

56°
52°
48°
44°
40°
116°
112°
108°
104°
100°
96°
PRECAMBRIAN
SHIELD
NFZ
NACP
ALBERTA
SASKATCHEWAN
MANITOBA
STURGEON L.
INTRUSIVE
PA
S
R
C
CN
SWEETGRASS-NORTH BATTLEFORD ARCH
SL
SG
BM
LR
HM
LB
JM
YD
CM
CZ
4
3
2
1
WILLISTON
BASIN
N. DAKOTA
S. DAKOTA
MONTANA
WYOMING
YV
TRANSCONTINENTAL ARCH
Mi 0 100
km 0 100 200
1 BLACK HILLS UPLIFT
2 MILES CITY ARCH
3 PORCUPINE DOME
4 BOWDOIN DOME
CENTRAL MONTANA IGNEOUS PETROGRAPHIC PROVINCE
SG SWEETGRASS HILLS
BM BEARPAW MOUNTAINS
LR LITTLE ROCKY MNTS.
HM HIGHWOOD MOUNTAINS
LB LITTLE BELT MNTS.
JM JUDITH MOUNTAINS
YD YOGO DYKE
CM CASTLE MOUNTAINS
CZ CRAZY MOUNTAINS
CN CROWSNEST VOLCANICS
YV YELLOWSTONE VOLCANICS
● ELBOW STRUCTURE
Φ CO2-INERT GASES
SL SHAUNAVON LINEAR
■ CITIES
R REGINA
S SASKATOON
PA PRINCE ALBERT
C CALGARY
NFZ NEEDLE FALLS SHEAR ZONE

Figure 1 – Location of the Sturgeon Lake kimberlitic intrusive with respect to some major structural features and other interesting phenomena of the Central Plains region. NACP = North American Central Plains Conductivity Anomaly.

Harper, C.T. (1989b): Kimberlites in the western Canadian sedimentary basin – an update; National Discussion Meeting, Canadian Continental Drilling Programme; August 28-29, 1989; Toronto.

Diamondiferous kimberlites have now been positively identified in north-central Saskatchewan, at Sturgeon Lake about 40 km northwest of Prince Albert. In mid-1988, when it became known that Monpros Limited, the Canadian subsidiary of the diamond giant, DeBeers Mining Company of South Africa, was actively exploring a property at Sturgeon Lake, the news fueled a staking rush which has now exceeded 400,000 hectares (800,000 acres). This is not the first indication that kimberlitic rocks and diamonds may be present in this region; unsubstantiated claims of diamond discoveries had been made in 1948 and 1961. In fact the kimberlitic rocks at Sturgeon Lake had been found by several local rock collectors in the mid-seventies, but the samples were not correctly identified. Kimberlites usually occur in clusters and according to industry reports low level airborne magnetic surveys have defined numerous exploration targets.

Kimberlites are defined as being volatile-rich, potassic, ultrabasic intrusives having a mantle source that occur as dykes, sills and narrow volcanic pipes. They commonly contain mantle xenoliths and have high pressure mineral assemblages including: olivine, phlogopite, serpentine, clino- and orthopyroxenes, pyrope garnets, carbonate and other accessory minerals. Some also contain diamonds. Kimberlites typically occur in old cratonic areas and or the stable platforms of continental areas. Intrusion generally occurs during epeirogenic movements (uplift or dilation) of the platforms, particularly along deep-seated fractures.

The Sturgeon Lake kimberlite intrudes Cretaceous strata and outcrops in a gravel pit near the present land surface. The pipe occurs near an abrupt change in the direction of the Sturgeon River/Lake channel. The pipe is located near the western margin of the subsurface projection of the Glennie Domain, a major lithostructural domain of the Canadian Shield. The western boundary of this domain is marked by the extension of the Needle Falls Shear Zone which also coincides with the North American Central Plains (NACP) conductivity anomaly. The Sturgeon Lake site also lies near the intersection of northwest- and northeast-trending topographic lineaments and subtle regional aeromagnetic features. The trends of the North and South Saskatchewan River valleys are also believed to reflect major basement structures. *Are the intersections of northwest and northeast structures a major controlling factor for emplacement of kimberlites in this region?*

Analysis of **topographic lineaments** in the southern part of the province indicates the importance of this orthogonal pattern of northwest- and northeast-trending structures. Some of these linears are also reflected in the subsurface outcrop patterns in the sedimentary basin. *Is it possible that other kimberlitic pipes might be located near the intersection of these major lineaments? Similarly, what is the significance of abrupt changes in the river channels of the North and South Saskatchewan Rivers and other waterways?*

It is interesting to note that **marls** exist and are still forming at Sturgeon Lake. The thickest part of the marl deposits lie opposite the location of the kimberlite. *Is there more than a mere coincidence between the presence of a carbonate-rich kimberlite and the presence of marls? Alternatively are the marls being formed from carbonate-rich solutions percolating up along fractures through underlying Paleozoic carbonates? Can this be used as an exploration guide?*

A distinctive **alkalic igneous province occurs** in central Montana. The Late Cretaceous to Eocene (54 to 44 Ma) igneous rocks occur as sills, laccoliths, stocks, dykes, diatremes and volcanics. Some of the diatremes have been identified as kimberlites, e.g. the Williams kimberlite in the Little Rocky Mountains area. Some of the dykes, such as the Yogo lamprophyre contain gem quality sapphires.

A cluster of alkalic intrusions occurs along the crest of the Sweetgrass Arch straddling the Montana-Alberta border. *Is it possible that the Sturgeon Lake kimberlite has a similar age and represents a northern extension of this igneous province? Do other intrusive uplifts exist between Montana and Prince Albert and for that matter in Alberta or Manitoba?* A recent news report states that Monopros has staked nearly 10 000 hectares in southwestern Saskatchewan lending some support to this idea.

Gas wells in the vicinity of the Sweetgrass-Arch cluster of intrusions contain high levels of CO_2 in association with nitrogen, helium and other rare gases. It has been suggested that the formation of the gases is genetically linked to these intrusions. Similar gas-enriched wells define a northeasterly trend from the southwest corner of Saskatchewan to a point about 200 km east of Prince Albert along or parallel to the Shaunavon Linear. Kimberlites are commonly rich in carbonate, and gas-rich inclusions in diamonds contain high levels of nitrogen and CO_2. *Can the presence of these gases be used as a guide to unexposed alkalic and/or kimberlitic intrusions?*

A number of other curious and anomalous structures in the sedimentary basin are also receiving renewed interest. One of these, the Elbow Structure, located south of the elbow in the South Saskatchewan River, has been variously attributed to cryptovolcanic (diatreme?), meteorite impact, salt intrusion and/or solution and thrust faulting processes as well as being thought of as non-existant. Its location near the intersection of sets of northwest and northeast lineaments is certainly favourable for something to have happened. The stratigraphic section below the Jurassic is reported to be highly disturbed. Exploration permits have also been taken out to cover this unusual feature.

Given the facts that most of the Western Canadian Sedimentary Basin is covered by a thick blanket of glacial debris and that kimberlite pipes are generally less than a few hundred metres diameter, it is not surprising that they have gone undetected for so long. It is very fortunate that their discovery has come before the CCDP has commenced its add-on or dedicated drilling program because a whole new field of investigation is possible. Perhaps some of the questions posed here may be answerable through the coordinated efforts of researchers involved in other aspects of the programme. Certainly a better understanding of basement tectonics along with the deformational and intrusive history of the basin could be extremely important in determining possible controls in trapping petroleum resources as well as defining loci for kimberlite emplacement. Such studies would also further our knowledge on the world-wide distribution

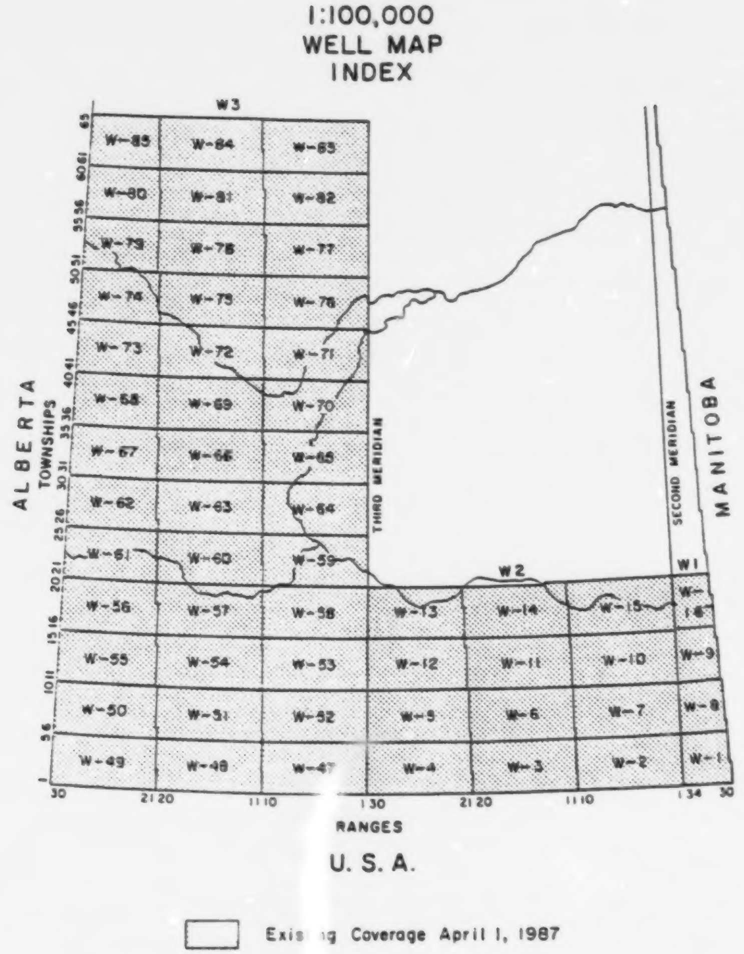

1:100,000
WELL MAP
INDEX
W3
W2
W1
W-85
W-84
W-83
W-80
W-81
W-82
W-79
W-78
W-77
W-74
W-75
W-76
W-73
W-72
W-71
W-68
W-69
W-70
W-67
W-66
W-65
W-62
W-63
W-64
W-61
W-60
W-59
W-56
W-57
W-58
W-13
W-14
W-15
W-16
W-55
W-54
W-53
W-12
W-11
W-10
W-9
W-50
W-51
W-52
W-5
W-6
W-7
W-8
W-49
W-48
W-47
W-4
W-3
W-2
W-1
ALBERTA
TOWNSHIPS
THIRD MERIDIAN
SECOND MERIDIAN
MANITOBA
65
6061
5556
5051
4546
4041
3536
3031
2526
2021
1516
1011
56
1
30
21 20
11 10
1 30
21 20
11 10
1 34 30
RANGES
U. S. A.
Exis[illegible]g Coverage April 1, 1987

Figure 1 - Distribution of the 1:10[illegible]000 scale Petroleum Well Location Maps available from Energy and Mines.

of kimberlite fields and basement control on basin development.

Harper, C.T., Bedo, J. and Kydd, P. (1989): The Saskatchewan Petroleum Well Location Map Series: A streamlined GIS application; paper presented at SASKGIS'89; Oct 17-19, 1989, Regina, abs.

Computerization of the Saskatchewan Petroleum Well Location Map Series was a joint venture GIS development project carried out by Saskatchewan Energy and Mines and Central Survey and Mapping Agency during the mid-eighties. Computerization was necessitated because of:

1) the tremendous increase in petroleum exploration drilling during the early 1980s,
2) a growing backlog in updating and replacing the existing manually produced maps, and
3) the need to produce better quality and more up-to-date maps for the petroleum industry, the principal consumer of the maps.

The map series, which utilizes a customized and simplified digital topographic base of the southern half of the province, depicts all oil and natural gas wells, along with their current status (i.e. dry, producing, abandoned, etc) and outlines of the various oil and gas pools. Presently 55 maps are available at 1:100 000 scale (Figure 1), from which more detailed maps of individual pools or specific areas can be extracted (e.g. for the quarterly land sales). Plans are in progress to complete the coverage of the eastern part of the province.

In addition coal lease and potash lease maps are produced from the same topographic base. In the near future, various disposition maps (e.g. helium, industrial minerals, etc) and the Mineral Claim Map Series for the northern part of the province will be added to the list of products available.

Macdonald, R., Beck, L.S. and Sibbald, T.I.I. (1989): Geological Survey impact on mineral discoveries: The Saskatchewan experience; Paper presented at Prospectors and Developers Association, Annual Meeting, March 1989, ext. abs.

The role of the Geological Survey in Saskatchewan in stimulating, assisting and helping to focus industry exploration may be illustrated through three examples: 1) the discovery of the Key Lake uranium deposits with the aid of exploration assessment file reports, 2) the development of the "unconformity-type" uranium model in the Athabasca Basin with major inputs through reconnaissance geological mapping, detailed studies and geological modelling, and 3) the advancement of gold exploration in the La Ronge and Glennie domains mainly through detailed bedrock remapping and application of the shear zone gold mineralization model.

Case 1: The Role of Mineral Assessment Records in the Discovery of the Key Lake Uranium Deposits

The Key Lake deposit, containing reserves of approximately 73,900 t (200 million lbs) of U_3O_8 in two orebodies grading 2.12 percent U_3O_8, is currently the largest uranium mine in the world. Major credit for the discovery of the Key Lake deposits must be given to the original joint-venture partners Uranerz and Inexco who located the deposit beneath 60-100 m of overburden several kilometres up-esker from the original discovery of mineralized fluvioglacial boulders. But why did they go there in the first place?

The history of the development of the "unconformity-type" uranium deposits associated with the Athabasca Basin starts with Gulf's discovery of the Rabbit Lake deposit in 1968. The exploration philosophy at that time was to seek uranium in the Helikian Athabasca sandstones, but the uranium was found instead in the underlying basement gneisses at or close to the Sub-Helikian unconformity. The high grade of the Rabbit Lake ore as it was then, the newness of the deposit-type in a large virtually unexplored sedimentary basin, together with the improved forecasts for uranium demand, precipitated a land staking rush unparalleled in Canadian mineral exploration history. By 1969 mineral permits covered the entire Athabasca Basin and about 70 percent of the Shield area.

Much of the terrain staked in this play was explored by airborne radiometric surveys and ground-checking but, with the exception of the discovery of the D-Zone by Mokta (Canada), later renamed Amok Ltd. in the Carswell Structure, no other discoveries were made, and by 1971 many of the permits had lapsed. Nevertheless, several companies continued their search by examining previous exploration work recorded in the non-confidential assessment files in Regina, as well as by continued field investigations. Calta Mines, a small Vancouver company who owned a permit covering the Key Lake area, had in 1969 outlined airborne anomalies east of Zimmer Lake as well as a weak but well-defined uranium-in-water anomaly in the lake itself. These anomalies were not pursued, however, and the permit was dropped.

Uranerz geologists who consulted the open assessment files in 1971, were impressed by the coincident untested radiometric and water geochemical anomalies described in the Calta report, and a prospecting team was dispatched immediately to Zimmer Lake. Within hours the first pitchblende-bearing boulder was discovered. These boulders were subsequently found to define a boulder train in eskerine glaciofluvial outwash. In 1974 the joint-venture group headed by Uranerz entered into partnership with the newly established Saskatchewan Mining and Development Corporation (SMDC). Extensive follow-up of the boulder train produced first in 1975 the Gaertner orebody several kilometres to the northeast, and in 1976 the Deilmann orebody along the same strike.

As can be seen from this example, the discovery and delineation of the Key Lake orebodies was brought about by a combination of investigations. Not least in this equation was the availability of the mineral assessment files held in the Geological Survey office in Regina.

Case 2: The Role of Reconnaissance Geological Mapping and other studies in Developing the Uranium Unconformity-type Model

The development of the unconformity uranium mineralization model was contributed to by bedrock reconnaissance mapping in the Key Lake area and largely developed through other studies taking place to the east at Wollaston Lake.

Reconnaissance bedrock mapping at 1:100,000 scale during the seventies arrived at a fortuitous moment during the uranium exploration industry operations in northern Saskatchewan. This mapping was started up in the summer of 1973, two years after the uraniferous boulders were discovered at Zimmer Lake, and was continued under the Canada- Saskatchewan 'DREE' program 1974-78. In the summer of 1976, G.E. Ray of the Survey mapped the Highrock Lake Sheet which covers the Key Lake Mine area. Preliminary results of this mapping were released in the Survey's Summary of Investigations in the fall of that year, and a final report was published in the following year. Apart from describing the regional bedrock geology of the area and confirming anomalously high concentrations of U-Ni-Co in Zimmer Lake, Ray's report paid special attention to the occurrence of uranium deposits, which he considered to be hosted in graphitic Aphebian metasediments at the base of the Wollaston Group, close to the contact with granitic gneisses which by now had been provisionally dated by Rb/Sr determinations as Archean.

The discoveries at Key Lake permitted comparison with the similar uranium unconformity association at Rabbit Lake, at least in general terms, although it elicited no common model for these deposits. In 1971, however, Gulf had discovered the 'A-Zone' deposit northeast of Rabbit Lake under Wollaston Lake. Drilling had revealed masses of high grade pitchblende in a clayey matrix overlying graphitic gneisses, a situation very different from that at Rabbit Lake. Unfortunately the drillcore recovery was poor and gave no enlightenment to Gulf, who continued exploring for deposits with Rabbit Lake features.

A clue to the 'A-Zone' puzzle was provided by F. Chandler in 1974 who conducted reconnaissance mapping in the Wollaston Lake area for the Geological Survey of Canada. His regional map distinguished metasedimentary rocks of what became to be known as the Wollaston Group from a group of granitic 'basement' gneisses. Their contact was, in fact coincident with the location of Gulf's A-Zone. When news of Ray's findings was received it became apparent that the A-Zone mineralization lay in a geologically analogous position to the Key Lake deposits. By tracing and drilling the graphitic rocks as indicated by the EM anomalies along the Aphebian/Archean contact, Gulf soon found another deposit, the Collins Bay 'B-Zone'. From these beginnings the unconformity model was developed into a general exploration model for the Athabasca Basin and, indeed, for other parts of the world.

Case 3: Advancing the Gold Exploration Play in the La Ronge and Glennie Domains

The Geological Survey programs mounted under the Canada-Saskatchewan Mineral Development Agreement 1984-89 have helped to fuel the pace of exploration for gold in the La Ronge and Glennie Domains, leading to the development of this new Canadian gold camp.

La Ronge Domain. - Gold occurrences had been known since the thirties in the La Ronge region of northern Saskatchewan. Exploration took a new turn in 1983 when exploratory drilling by SMDC in joint venture with Starrex Mining at Star Lake encountered several impressive intersections at what came to be known as the '21 Zone'. This zone comprises a pyritic quartz vein within a major shear zone traversing the Star Lake Pluton. The best hole returned 15.4 m (50.5 ft) grading 42.92 gm/t (1.26 oz/ton) Au between 69.09 and 84.4 m (226.5 and 277 ft). An extensive diamond drill program was carried out through 1984 and drill reserves of 233,700 t grading 17 g/t (0.5 oz/ton) were outlined by the end of 1984. A development decision was made in mid-1985 and the first full brick was poured in January 1987.

During a routine soil sampling survey in 1984 on the nearby Mahogany Mineral Resources property, a highly auriferous quartz vein was discovered at what is now known as the Rod Zone. Out of this occurrence has developed the Jolu Mine, which poured its first brick in late 1988. Some 678,700 t grading 13.15 g/t (0.386 oz/ton) have been categorized as proven and probable. Here, as in some of the more recent developments in the La Ronge Belt, the quartz veins are hosted in a shear zone. There has been extensive industry activity in the La Ronge belt since 1984, and a number of deposits are likely to develop into mines.

'Gold Belt Geology' studies comprised the main part of a new Canada-Saskatchewan Mineral Development Agreement 1984-89. This agreement was set up with a stronger commodity bias than the earlier DREE agreements of the seventies, when the emphasis was on the completion of primary reconnaissance coverage of the Shield. During the planning stage of the program in 1983-84, the Canadian commodity interest was distinctly aligned with gold and precious metals, and this emphasis was selected for the agreement.

The first project under this program was to commission 'Gold in Saskatchewan', a review by Coombe Consultants Ltd. of the then existing gold occurrences in the province. This review was produced at breakneck speed for presentation at the Saskatchewan Geological Survey Open House meeting in the Fall of 1984, and was clearly a timely document for the exploration industry.

The major thrust of the 'Gold Belt Geology' program was the commencement in the summer of 1984 of a program of 1:20,000 remapping of the bedrock geology of the La Ronge 'Gold Belt'. Previous mapping of the belt had been completed at a scale of 1:63,360 mainly during the fifties and sixties. The 1:20,000 maps provided a much needed 'road map' for industry. They showed a finer break down of lithological subdivisions, and delineated shear and fault zones. The reports typically provided tectonic and metallogenic models, and most also suggested 'regional exploration targets'.

The Star Lake Pluton was mapped by D.J. Thomas in the summer of 1984, concurrently with the 21 Zone diamond drill program. There was considerable exchange of information and ideas between the survey and exploration geologists in the field, and this continued during the ensuing winter, leading to the development of a shear zone model for gold mineralization.

Glennie Domain. - The geological similarity of the La Ronge and Glennie Domains had been pointed out for several years prior to the gold exploration of the 1980s by J.F. Lewry of the University of Regina and others. The metavolcanic rocks of the Glennie Domain occur in narrower arcuate belts than in the La Ronge belt, but nonetheless were generally considered to be broadly equivalent in lithology and general age. Lewry considered the Glennie volcanics to be allochthonous nappe sheets derived from the La Ronge rocks to the west, and postulated the presence of major high strain zones separating the major thrust sheets.

Until well into the 1980s there had been relatively little industry activity in the Glennie Domain, except at the Seabee deposit at Laonil Lake. Originally staked by Cominco in 1949, the company put down 117 drillholes over the next 35 years and dug several trenches. In 1984 the property passed into the hands of Claude Resources. Following a joint venture agreement with Placer in 1985, a total of 72 new holes were drilled to a depth of over 1000 ft (366 m) and extensive overburden stripping was carried out which defined reserves announced in 1987 of approximately 2 million tonnes at an average grade of 6.3 g/t (0.185 oz/ton) of which about one-third graded 12.4 g/t (0.364 oz/ton). In 1987 Placer completed an underground decline and conducted further feasibility studies. After Placer withdrew from the option in 1988, Claude Resources commissioned ACA Howe International to complete an ore reserves estimate. A December 1988 news release gave proven and probable reserves of 655,300 t at 12.4 g/t (0.365 oz/ton), possible 372,870 t at 12.4 g/t (0.365 oz/ton), and about 1,016,000 t of inferred ore. A production decision is expected from Claude in the Spring of 1989. The Seabee mineralization is open ended to the east and west, and it may be noted that Placer Dome has retained joint-venture interests in surrounding properties.

Bearing in mind the new drilling going on at Seabee and other prospects along the Reindeer River, G.D. Delaney of the Survey spent the summers of 1986 and 1987 in 1:20,000 revision mapping of the area between Laonil, Carruthers and Uskik Lakes. The mapping provided regional information concerning the tectonic and metallogenic style of the northern part of the Glennie Domain with a strong focus on the geology of the Seabee deposit itself.

The host rock of the Seabee auriferous quartz veins is a fine grained rock which was interpreted at first by the Claude geologists to be tuffaceous horizons, in analogy with the Hemlo model. Lewry who made the first 'one inch' map of the area, considered drillcore samples from Seabee, however, to be sheared rocks, possibly derived from plutonic protoliths. This idea was reinforced by Delaney's work, who interpreted the host to the quartz veins as shear zones which are genetically related to a major shear zone south of the deposit. Shear zone-hosted auriferous quartz veins have been discovered recently by Calpine Resources near Eisler Lake to the south.

Field mapping in the southern part of the Glennie Domain in 1988 has further served to illustrate the importance of tectonic controls of gold mineralization. The definition of large and small scale high strain and ductile shear zones has already helped to focus current exploratory drilling for example in the Brownell Lake area and is providing a better geological understanding of the new Saskatchewan Gold Camp.

Conclusion

The contribution which the Geological Survey has made to mineral discoveries in Saskatchewan has been largely due to the high degree of cooperation between the provincial and federal agencies, universities and not least with industry. This points the way to future increased cooperation in regional geoscience and technology programs between these organizations.

MacDougall, D.G. (1989): Metallogenic Map Series, Ile-à-la-Crosse, NTS Area 73O; Saskatchewan Energy and Mines, Report 234, 14p, (accompanied by 1:250 000 scale map).

Schwann, P.L. (1989): Petrography, geochemistry and platinum-group element distribution of part of the Upper Central Layered Zone, Main Layered Series, Fox River Sill, Northeastern Manitoba; unpublished M.Sc. thesis, Carleton University.

The Proterozoic (1882.9 Ma) Fox River Sill (FRS) is a 275 km long, 2 - 2.5 km thick mafic - ultramafic intrusion located along the Churchill-Superior Boundary Zone of northeastern Manitoba. It has been subdivided into a lower Marginal Series, a Layered Series and an upper Hybrid Series. The Layered Series is further subdivided into the Lower Central Layered Zone (LCLZ) and the Upper Central Layered Zone (UCLZ). The study interval covers the LCLZ/UCLZ contact and the lower 600 m of UCLZ strata. Within this interval a minimum of 32 cyclic units are recognized, composed of variations in dunite (cumulus ol ± chr), peridotite (cumulus ol ± cpx ± chr), pyroxenite (cumulus cpx ± ol ± chr) and gabbro (cumulus pl ± cpx ± ol). Disseminated sulphides (po + pn + ccp + cbn + mkw + py) occur throughout the stratigraphic successions as polymineralic or monomineralic grains. Sulphide assemblages range from Ni-rich in peridotite to more Cu-rich in pyroxenite. Primary sulphides have been replaced and/or recrystallized by silicate, oxide and second-generation Cu-rich sulphide assemblages.

Within the 32 cyclic units there are three main intervals of anomalous platinum-group element (PGE) concentrations (Pt + Pd 100 ppb); Lower Mineralized Unit (70 m), Middle Mineralized unit (50 m), Upper Mineralized Unit (5 m). Within these intervals, PGE abundances occur predominantly within sulphide-bearing, medium to coarse-grained olivine clinopyroxenite and are commonly associated with high Cu, S and Se abundances. However correlation coefficient analyses for 1 m long drill core intervals indicate a moderate to poor correlation between PGE and base metal element abundances.

Pt/(Pt + Pd) ratios and Chondrite Normalized Profiles (CNP) indicate that with increasing stratigraphic height, Pd is depleted relative to Pt. S isotope data is notably heavy (+9.2 – +17.4) indicating that crustal S has been incorporated into the magma.

Slimmon, W.L. (1989): Compilation Bedrock Geology, Fond-du-Lac, NTS Area 74O, Saskatchewan Energy and Mines, Report 247 (1:250 000 scale map with marginal notes).

Watters, B.R., Thomas, D.J. and Harper, C.T. (1989): Geochemistry and evolution of Proterozoic granitic intrusions in the La Ronge Domain of northern Saskatchewan, Canada; presented at Symposium on Precambrian Granitoids; ICGP Aug. 14-17, 1989, Helsinki, Finland, abs.

Granitic intrusions comprise a significant component of the Central Metavolcanic Belt (CMB) of the La Ronge Domain in the Saskatchewan segment of the Trans-Hudson orogen. The CMB is regarded as representing an island arc complex, of predominantly ensimatic character, developed during the Early Proterozoic (ca. 1880 Ma). The major intrusions were emplaced syntectonically, closely following the development of the volcanic complex. Radiometric age determinations for the granite intrusions range from 1866 to 1834 Ma with a peak at about 1855 Ma.

Three main types of granitic intrusion can be identified: Type 1 - composite, zoned intrusions with a wide compositional range extending from gabbro and diorite to granite; Type 2 - relatively homogeneous intrusions with a more restricted compositional range of predominantly granodiorite to granite; Type 3 - homogeneous, quartz-rich leucocratic granite intrusions.

Lithologic and chemical variation in Type 1 intrusions is both gradational and sharp, with the earliest phases of intrusions being the most mafic and successive phases becoming progressively more felsic. All types are typically calc-alkaline and display chemical compositional affinities with much of the volcanic assemblage. Major and trace element compositions (including REE) of constituent zones and phases of Type 1 intrusions form coherent and overlapping trends. Chemical characteristics of Type 2 and Type 3 intrusions are similar to the intermediate to felsic members of the Type 1 intrusions.

The three types of intrusion are regarded as representing different stages in an evolutionary sequence. The geochemical data are consistent with an origin for the granitic and related magmas by partial melting of garnet-bearing amphibolitic source rocks, representing metamorphosed mafic to intermediate volcanics in the root zones of the arc complex. Variable degrees of partial melting produced a range of magma compositions which were modified by fractionation involving amphibole as the principal fractionating phase. Much of the fractionation is likely to have occurred in reservoirs beneath the sites of emplacement. *In situ* fractionation and contamination by volcanic country rock are regarded as subordinate processes. The application of geochemical discrimination criteria provides clear evidence for a volcanic arc character for the intrusions and low initial $^{87}Sr/^{86}Sr$ ratios, in the range 0.7016 to 0.7020, further support this conclusion.

1. Reports Reprinted in 1989

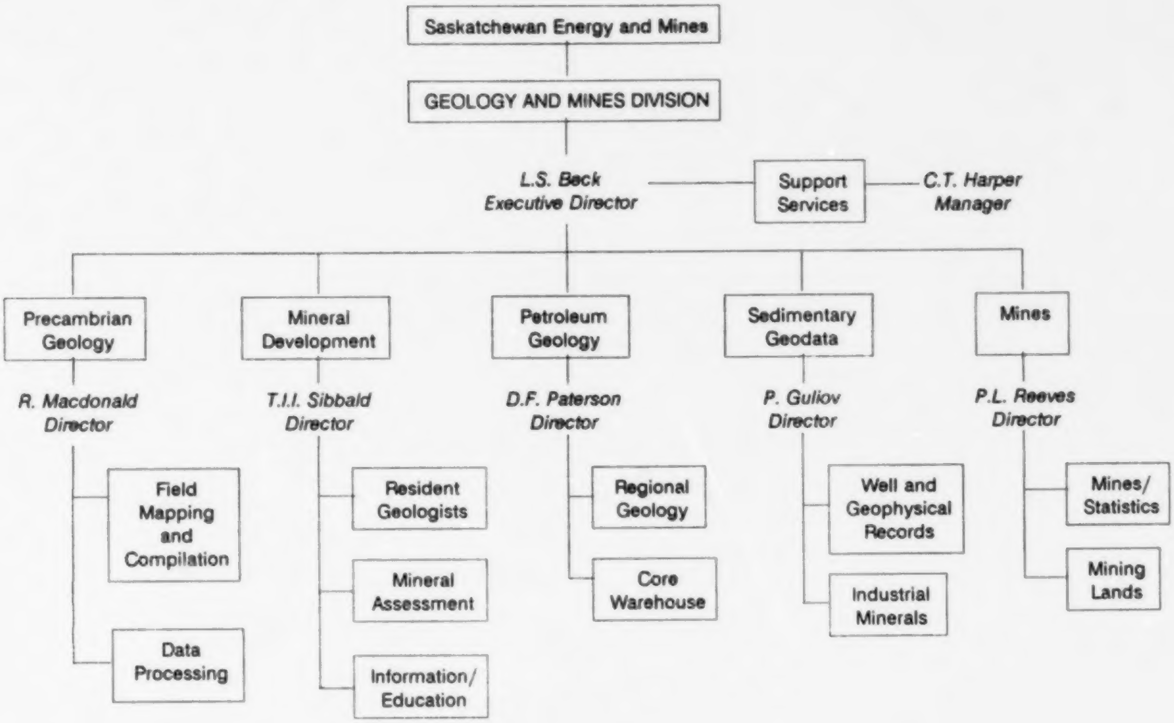
Byers, A.R. and Dahlstrom, C.D.A. (1954): Geology and mineral deposits of the Amisk - Wildnest Lakes area, 63L-9, 63L-16, Saskatchewan; Saskatchewan Energy and Mines, Report 14, 177p.

Byers, A.R. Kirkland, S.J.T. and Pearson, W.J. (1965): Geology and Mineral deposits of the Flin Flon area, Saskatchewan; Saskatchewan Energy and Mines, Report 62, 95p.

Acknowledgements

The project leaders acknowledge the assistance, in the field, of Rob Barber, Brent Czornobay, Cindy Swiney, Thinh Nguyen, Tai Huu Nguyen, Darwin Frehlick, Robert Stevens, Darin Wright, Andrew Wallace, Ken Conley, Tim Mackay, Ron Gall, Kent Wilkinson, Gary Pon, Jason Sturgeon, Jason Levers, Kent Ellmers, Pamela Cook, and Mark Sombach.

The editors are grateful for assistance given in the editing and production process by Horst Stolz, Rick Bennett, David MacDougall, and Brent Czornobay. Desk-top publishing of the report was handled by Jagdish Bilkhu and Verna Ziegler. Pat Kydd, Ken Jones and Phil Weir handled preparation of some of the figures and, with assistance from Jim Bedo, Rick Pearce and Harry Buyze, assembled the manuscript maps.


Saskatchewan Energy and Mines
GEOLOGY AND MINES DIVISION
L.S. Beck
Executive Director
Support Services
C.T. Harper
Manager
Precambrian Geology
R. Macdonald
Director
Field Mapping and Compilation
Data Processing
Mineral Development
T.I.I. Sibbald
Director
Resident Geologists
Mineral Assessment
Information/ Education
Petroleum Geology
D.F. Paterson
Director
Regional Geology
Core Warehouse
Sedimentary Geodata
P. Guliov
Director
Well and Geophysical Records
Industrial Minerals
Mines
P.L. Reeves
Director
Mines/ Statistics
Mining Lands

The Saskatchewan Geological Survey comprises the geoscience activities of the Precambrian Geology, Mineral Development, Petroleum Geology and Sedimentary Geodata Branches.

Saskatchewan Energy and Mines; Geology and Mines Division, September 14, 1989

Back Row (left to right): Dave MacDougall, Bob Troyer, Rick Bennett. *5th Row:* Craig Zborowski, Dave Thomas, Laura Smith, Judy Adams, Bill Slimmon, Vivien Bohn, Rita Kovacevic, Linda Troesch, Blaine Scott. *4th Row:* Brian Reilly, Jagdish Bilkhu, Gary Delaney, Don Forsberg, Bob Lavigne, Dave Gallant, Gil Lopez, Kim Kreis. *3rd Row:* Leanne Sutyla, Terry Ell, Chris Gilboy, Dave Lane, Harry Buyze, Phil Weir, Pat Kydd, Jim Bedo. *2nd Row:* Kelly Klyne, Lisa Hagen, Verna Zeigler, Malcolm Gent, Norman Lee, Fran Haidl, Sherry Richardson, Nancy Richmond, Jeanne Tanouye. *Front Row:* Phil Reeves, Paul Guliov, Bob Macdonald, Les Beck (Executive Director), Doug Paterson, Tom Sibbald, Charlie Harper.
Missing: Kerry Barrett, Rick Pearce, Rod McCall, Mary McNally, Ken Jones, Horst Stolz.

Precambrian Laboratory, La Ronge, April 1989

(Left to right): Andrew Gracie, Wendy Hounjet, Pam Schwann, Joan Drever.

Please add my name to the mailing list for:

- ☐ Catalogue of maps, publications and services (free of charge)
- ☐ Notice and Results of Sale of Petroleum and Natural Gas Rights (free of charge)
- ☐ Annual Report (free of charge)
- ☐ Lapsed Precambrian Mineral Dispositions (free of charge)
- ☐ Summary of Investigations ($25.00)
- ☐ Reservoir Annual ($60.00)
- ☐ Statistical Yearbook ($40.00)
- ☐ Reservoir Performance Charts ($60.00)
- ☐ Saskatchewan Energy and Mines Manual ($75.00 includes updates for current year)
- ☐ Drilling Activity Report ($120.00)
- ☐ Monthly Oil and Gas Production Report ($120.00)
- ☐ Oil and Gas Units ($60.00)
- ☐ Schedule of Wells ($250.00)
- ☐ Saskatchewan Pool Boundary Maps ($90.00)

☐ $ __________ enclosed ☐ Please bill me

Name ______________________________

Company ______________________________

Address ______________________________

Postal Code ______________________________

Signature ______________________________

Mail to:

Saskatchewan Energy and Mines
Marketing and Publications Branch
1914 Hamilton Street
Regina, Saskatchewan
S4P 4V4

November 1989

SASKATCHEWAN GEOLOGICAL SURVEY

Staff as of November 1, 1989

At Toronto Dominion Bank Building, Regina:

Geology and Mines Division Administration

Executive Director	L.S. Beck, *Ph.D, P.Eng.*
Secretaries	J. Adams V. Ziegler

At Toronto Dominion Bank Building, Regina:

Precambrian Geology Branch

Director	R. Macdonald, *Ph.D., P.Eng.*
Field Mapping and Compilation:	
Geologists	D.J. Thomas, *M.Sc.* G.D. Delaney, *Ph.D.* B.A. Reilly, *M.Sc.*[1] W.L. Slimmon, *B.Sc.*[1]
Office Geologist	B. Czornobay, *B.Sc.*[1]
Data Processing:	
Geologist	N. Lee, *M.Sc.*[3]
Secretary	J. Bilkhu[2]

Mineral Development Branch

Director	T.I.I. Sibbald, *Ph.D., D.I.C.*
Information/Education:	
Geologists	D.G. MacDougall, *B.Sc.(Hons.)* B.P. Scott, *M.Sc., P.Eng.*
Mineral Assessment:	
Geologists	H. Stolz, *B.Sc.* R.W. Bennett, *B.Sc.(Hons.), P.Eng.*
Geological Assistant	L. Smith, *B.Sc.*
Resident Geologist Offices:	
La Ronge:	
Geologists	A.J. Gracie, *Ph.D., P.Eng.* P.L. Schwann, *M.Sc.*
Clerk	J. Dreaver

At Toronto Dominion Bank Building, Regina:

Sedimentary Geodata Branch

Director	P. Guliov, *M.Sc., P.Eng.*
Industrial Minerals:	
Geologist	M.R. Gent, *M.Sc.*[1]
Well and Geophysical Records:	
Geologist	D.R. Troyer, *M.Sc., P.Eng.*
Coding Clerk	R. Kovacevic
Well File Clerk	J. Tanouye
Geophysical Clerk	K. Barrett

At 201 Dewdney Avenue East, Regina:

Petroleum Geology Branch

Director	D.F. Paterson, *Ph.D., P.Eng.*
Regional Geology:	
Geologists	C.F. Gilboy, *Ph.D., P.Eng.* F.M. Haidl, *M.Sc.* L.K. Kreis, *B.Sc.* S. Richardson, *B.Sc.*[1]
Warehouse:	
Warehouse Supervisor	D. Forsberg
Warehouse Staff	R.L. McCall R. Lavigne D. Gallant
Secretaries	M. McNally L. Sutyla

At Toronto Dominion Bank Building, Regina:

Support Services Section

Manager	C.T. Harper, *Ph.D., P. Eng.*
Review Geologist	N.M. Richmond, *B.Sc.*
Geological Survey Drafting Unit:	
Supervisor	R.P. Kydd
Draftspersons	P.A. Weir K.G. Jones
General Drafting Unit:	
Supervisor	J.J. Bedo
Draftspersons	R.O. Pearce A.H. Buyze

---

[1] position contracted under Saskatchewan Mineral Industry Diversification Program 1989–90

[2] also serving Mineral Development Branch

[3] seconded to Mines Branch temporarily